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The method and scope of science

The Renaissance, especially that particular feature of it known as the Revival of Learning, was marked by the growth of a new independence of thought. The scholars, the poets, and the artists of Europe were no longer content to seek their inspiration in the teaching of the schoolmen, in ecclesiastical dogma, or in any of the modes and habits of the Middle Ages, then drawing to a close. The new intellectual adventurousness led men to shake themselves free of tradition and sent them back to the great thinkers of classical Greece and Rome.

It would, however, be incorrect to imagine that this new freedom was born fully grown. On the contrary, in its infancy it achieved little beyond the exchange of one set of authorities for another. The scholastic pedants might be despised or ignored, but the writings of Hippocrates, Plato, and Aristotle were at first accorded the same uncritical acceptance as had formerly been given to those of Abelard, Albertus Magnus, and Thomas Aquinas. The works of the great philosophers of antiquity were in fact received for a time as true in their entirety, instead of being subjected to that critical scrutiny without which real progress is impossible. There was indeed no lack of men able to develop logical arguments; but logical arguments based on false premises could lead only to false conclusions, even though the premises were drawn from Aristotle himself.

Nevertheless the first and most difficult step had been taken, and men gradually began to perceive that the very reasons which had led to the overthrow of medieval authority made it necessary also to question the infallibility of the more remote past. Their growing self-confidence restrained them from a too credulous trust in statements the truth of which they had not tested for themselves, however celebrated the source; and when this second stage had been reached the way was open for rapid advance.

In this issue we publish an article marking the four-hundredth anniversary of the birth of Tycho Brahe. Brahe made a contribution to science which reached far beyond his immediate work in astronomy, in which field it enabled Kepler to formulate the laws of planetary motion. He clearly recognized and stated that an essential preliminary to argument and the formation of theories must be the collection of relevant facts by observation or experiment. This experimental method was accepted by Boyle, Newton, and the other great natural philosophers of the age, and is essentially the same as the 'scientific method' so widely used today. This implies the investigation of natural phenomena by the observational and experimental collection of facts, and the use of these facts to form a theory. This theory is used in turn to make predictions which can be tested by further observations and experiments. If the predictions prove correct, then the pragmatic truth of the theory is the more firmly established; if the predictions are incorrect, then the theory must be modified, or even abandoned, in the light of new facts.

The scientist's readiness to jettison theories is commonly misunderstood by the layman, who regards it as a sign of weakness and confusion. Science, he says, is continually offering different explanations of phenomena, and the statement implies an unfavourable criticism. It suggests, in fact, that the teachings of science are unreliable because their mode of expression is variable. This is plainly a fallacy, but it is so widely held as to form one of the chief stumbling-blocks to the lay comprehension of science. Perhaps the best way to remove it would be to make clear that by 'explanation' the scientist means no more than 'description,' or, more precisely, description of the unfamiliar in terms of the familiar. When this point is made the rest is simple, for descriptions of

the same phenomenon or set of phenomena may vary in degree of accuracy or completeness. A child might describe a cow as a four-legged animal which eats grass and gives milk, and the description would be a true one. To describe a cow as the mature female of wild or domestic cattle of the genus *Bos* is equally accurate, but both descriptions lack completeness. A scientific theory has similar limitations of accuracy and completeness, and when an old theory is abandoned in favour of a new one the reason is either that the old theory did not give an accurate description of the phenomena concerned or that it was found to be lacking in completeness. Now, in the description of nature, perfect accuracy and perfect completeness are unattainable ideals, but what the scientist tries continually to do is to approach these ideals more closely. The scientific method does not elevate its theories to the rank of dogma but rather classes them with test-tubes and balances as necessary equipment.

This scientific method has proved of immense value in all the physical sciences, and is largely responsible for the speed with which scientific knowledge has increased during the past three centuries. Today it is so universally used by men of science that its comparatively recent origin is difficult to realize. It is, however, imprudent to judge that the scientific method must necessarily provide a means of solving all kinds of problems outside the physical sciences. Powerful though it is, the method is neither omnipotent nor foreseeably likely to become so. Even within mathematics and the physical sciences it has its limitations. The differential equations of modern physics are often solved by intuitive rather than by rigorous methods. Heisenberg's uncertainty principle, which now seems to be of such wide application, suggests that a single set of observations, however precisely made, may be capable of several alternative interpretations, to any one of which is it possible to assign only a degree of probability. The modern physicist is inclined to abandon the idea that the future is inherent in the present.

The scientific method in its simple form has had to be modified when dealing with natural phenomena where many variables exist and where control experiments are impracticable. In such cases statistical methods have proved invaluable. Meteorology, subject of Sir Nelson Johnson's article in this issue, provides many problems of this kind. Recent work has led to great advances in methods of collecting data relating to such variables as pressure, temperature, humidity, and wind velocity; but in interpreting these data one must, for the present at least, be content with probabilities rather than with certainties. A modern weather forecast cannot claim to state what the weather will be: it states what the weather is likely to be.

It is, however, in the realm of qualities not susceptible of measurement of any kind that the scientific method—as far as it has yet developed—ought frankly to be recognized as inapplicable. An obvious example can be taken from the field of art. The scientific method can give a great deal of information on the chemical nature of pigments, on the wavelength of the light they reflect, and on similar factors, but it is wholly unable to predict whether a picture will have an aesthetic appeal to those who see it. Nor can the scientific method be of help in those problems relating to drama, literature, and the like, which involve qualities that cannot be measured and knowledge which is not communicable. In the wide field of human affairs the scientific method cannot be applied, even in the form of statistical analysis, to problems in which events are influenced by the philosophical values of goodness, truth, and beauty, and emotions such as patriotism, fear, or political conviction.

There are those who see in science the surest road to human betterment; there are, too, those who see in science the impending ruin of the world. Wherever the truth lies between these extremes, it is at least indisputable that science must have a profound and increasing influence on the future of man. It is therefore essential that those charged with the responsibility of making great decisions should clearly recognize not only the scope but also the limitations of science as it is now conceived.

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Some recent aspects of meteorology

SIR NELSON JOHNSON

In spite of the fact that the phenomena of weather have forced themselves upon the notice of man since the earliest times, meteorology is a young science, for it is only comparatively recently that circumstances have permitted an effective scientific approach to the subject. In this article are discussed the factors which for so long retarded the scientific study of the weather, and the main lines along which the subject is now being actively pursued.

From the time of the ancients up to the nineteenth century, philosophers attempted to explain the sequence of weather they experienced at a particular place. But it proved a complete enigma. There appeared no rhyme or reason in it, and the situation was epitomized in the well-known phrase—'the wind bloweth where it listeth.'

In the course of time, workers out of doors gradually found that certain aspects of the heavens appeared to presage rain or fine weather, and the folk-lore of the Shepherd of Banbury grew up. Most of these 'rules' covered only a few hours ahead, and while a small number of them possessed an element of truth, the majority were devoid of any foundation in either fact or theory. The reader who is interested in this particular aspect of the subject is recommended to read a book recently published[1] in which the Shepherd of Banbury, *et hoc genus omne*, are subjected to critical examination.

Observation at a single point is still perforce the only method of study in many instances. In such cases a statistical treatment of the data becomes necessary. With many meteorological elements, however, departures from the mean are so large that the mean deviation of the observed quantity is frequently nearly as important as the mean value itself.

Before leaving the case of the single observer, it may be noted that there are instances where 'single-observer forecasting' has to be practised even today, such as in an isolated ship at sea. Modern knowledge of pressure systems and 'fronts,' however, enables a meteorologist to achieve a moderate degree of success in the interpretation of his own observations, but it is never a method to be employed if reports from surrounding places can be obtained by any possible means. International collaboration and the use of radio fortunately render it comparatively rare for a meteorologist to have to attempt single-observer forecasting.

The invention of the barometer in 1643 and the discovery that atmospheric pressure is subject to variation were, of course, epoch-making events. They failed, however, to lead immediately to the advance in the dynamics of meteorology which might have been expected.

The true light first began to dawn when the step was taken of plotting the observations made simultaneously over an area. This did not occur until early in the nineteenth century, but it at once brought to light the relation between pressure and wind, and it showed the organic structure of the depression. It revealed it as a huge vortex, and paved the way for the mathematical treatment of two generations later.

But progress was still slow, since the collection of observations from an area was a formidable undertaking in those days. It was the invention of the electric telegraph about the middle of the century that revolutionized the position. It soon became possible to plot 'synoptic' charts covering a wide area every day. The international exchange of observations became a necessity, and the second half of the century saw much effort expended on establishing international co-operation on a sound basis.

Although forecasting was still largely empirical, the physical and dynamical study of pressure systems continued. The co-existence in depressions of warm air currents from equatorial regions and of cold currents from the Arctic was recognized, and mathematicians attempted to discover under what conditions two such currents in juxtaposition would remain stable. But it was not until the second decade of the present century that the Norwegian meteorologists Bjerknes, father and son, produced a theory that was satisfactory both physically and mathematically.

[1] G. Kimble and R. Bush. *The Weather* (Pelican Books).

According to the Bjerknes theory, a depression develops at a point on the boundary between a warm and a cold air current. The warm air forms a bulge in the cold current and the centre of the cyclone occurs at the apex of this bulge, or 'warm sector.' The structure is seen in figure 1. The leading edge of the warm sector is known as the 'warm front' and is characterized by the warm air sliding up over the cold air along a sloping surface, the inclination of which to the horizontal is about 1/150. The trailing edge of the warm sector is the

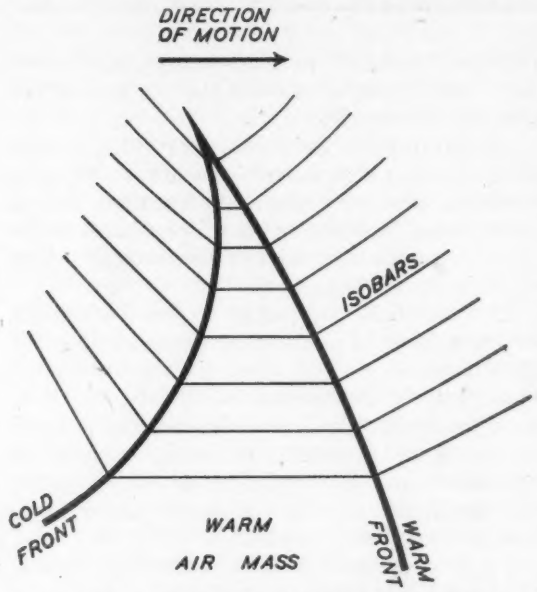


FIGURE 1 – *Structure of a depression (after Bjerknes).*

'cold front,' and here the cold air drives a wedge under the warm air, lifting it off the ground. The angle of the wedge is about 1/50. The combined effect of these two processes is to narrow the warm sector until eventually the whole of it has been lifted off the ground. From this point onward the depression diminishes in intensity.

The experience of the last thirty years has shown that the Bjerknes theory is a most valuable working hypothesis for the purposes of forecasting, and there seems little reason to doubt that it is correct in at least its essential features. For our present purpose its most interesting feature consists in the introduction of the vertical dimension. It is no longer sufficient to think of a depression as something happening close to the ground. Attention must be paid to what is occurring from sea-level up to the base of the stratosphere, and possibly within the stratosphere itself.

Although the need for information about the movement and physical conditions of the upper air was thus made apparent, it is only in the course of the last few years that means have been devised of obtaining this information on a routine basis. It is in this field of technique of observation that the most important advances have recently been made. A description will therefore be given of some of these new observational methods, together with an indication of the manner in which the information so obtained is used.

One of the most valuable pieces of upper-air information required by the meteorologist is a knowledge of the air movements aloft. Not only does it enable him to advise the aviator of the navigational wind which he will encounter, but it is also of prime importance in connection with the dynamics and persistence of both cyclones and anticyclones.

The normal method of measuring the upper wind is by following a pilot balloon by means of a theodolite. The method is, however, subject to the serious limitation that it cannot be used when the sky is clouded. Two methods have been developed which overcome this limitation. The first makes use of radio direction-finding, and the second employs the modern radar technique.

In the first method three radio direction-finding stations are set up on the ground in the form of a triangle of about 40 km. length of side. From a control station near the centre of this triangle a balloon of about 2 m. diameter is released, carrying a small radio transmitter. The balloon is filled with hydrogen to rise at about six metres per second, and its radio emissions enable it to be followed by the three direction-finding stations. The bearings of the balloon from each station are plotted every minute, the intersection giving its track, from which the wind speed and direction are immediately obtained. The balloon usually reaches a height of about 18 km. before bursting, when a parachute brings the transmitter down to earth again.

The direction-finding equipment employed at the three observing stations was developed by the National Physical Laboratory, Teddington. It consists essentially of an Adcock H-type aerial with vertical dipoles and capable of rotation about a vertical axis. The receiving circuit is tuned to the frequency of the balloon-borne transmitter, and the bearing of the latter is found by rotating the aerial until silence in the telephone shows that the aerial is normal to the incoming wave.

In order to secure accurate results by this

method, strict attention must be paid to a number of points. Accurate symmetry in the construction of the Adcock H-aerials is, of course, essential, but precautions must also be taken to eliminate any possible refraction of the incoming radio beam. All iron must be rigorously excluded from the construction of the observing huts: there must be no metal fences, power lines, buildings, trees, or hedges in the vicinity, while the site must be level and possess a uniform subsoil.

These rather severe restrictions, combined with the fact that three observing stations are necessary, are gradually causing this method to give way to the radar method described below. During the past six years, nevertheless, the direction-finding method has proved of the greatest value and has yielded most important results.

In the second, or radar, method of wind-finding the course of a similar free balloon is again followed. In this case a radar transmitter at the observing station is used to direct radar pulses towards the balloon, which carries a special device for reflecting the pulses back to the radar receiving set. The receiving set is located beside the transmitter and gives measurements of the azimuth, elevation, and slant distance of the balloon. From these three quantities simple trigonometry enables the course of the balloon to be computed from minute to minute.

The actual form of the ground equipment is briefly as follows: the short-wave radar transmitter and receiver are housed in a lorry trailer, the emitting and receiving antennae being situated at the foci of two paraboloidal mirrors of 4 ft. diameter mounted on the roof. The two mirrors are carried side by side on a framework which can be rotated both in azimuth and elevation. The operator manipulates the system until a maximum strength of returned signal is received, showing that the axes of the two mirrors are directed at the balloon.

The special reflector carried by the balloon makes use of the principle of the 'corner reflector.' Three mutually perpendicular surfaces, such as are found in the corner of a box, possess the property of reflecting any incident beam back along its path. For wind-finding purposes, a reflector is made by stretching metallic paper on a light wooden framework arranged to form three intersecting surfaces—one horizontal and two vertical (figure 2). Although this reflector necessarily swings as it hangs below the balloon, its ability to turn a beam through 180° means that the radar pulses reaching it are always sent back at maximum intensity to the ground receiver.

The type of result given by the two methods of wind-finding just described is illustrated in figure 3, which shows the wind structure on 9th November, 1944. At noon on that day (graph *A*) the maximum wind speed occurred at a height of 10 km., with a value of 41 metres per second. By midnight (graph *B*) the wind velocity at the same height had increased to 102 metres per second (220 miles per hour). Until these modern methods of wind-finding became available wind velocities of this magnitude were not suspected, since they occur in cyclonic conditions when the sky is heavily clouded. Even more striking than the actual velocity, perhaps, is the rapidity with which the speed increased in the course of twelve hours.

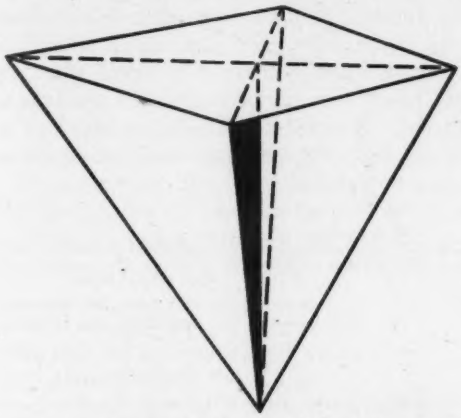


FIGURE 2 – *'Corner reflector' carried by balloon in wind-finding by radar.*

As already mentioned, these methods of wind-finding are at present limited to a height of about 18 km. During the war an opportunity occurred for measuring the wind at a height of 30 km. Although the method does not lend itself to routine use at stations generally, it has yielded results of unusual interest and importance. The method involves the use of a special gun, which fires a shell upwards at very high velocity. The shell is fuzed to burst at the vertex of its trajectory, and produces a smoke puff which can be followed by means of theodolites on the ground. A series of measurements made in south-east England at approximately fortnightly intervals over a period of fifteen months has shown that during winter the wind at a height of 30 km. is mainly westerly, while during summer it is predominantly easterly. The change-over takes place about April and October. It was further found that the winter

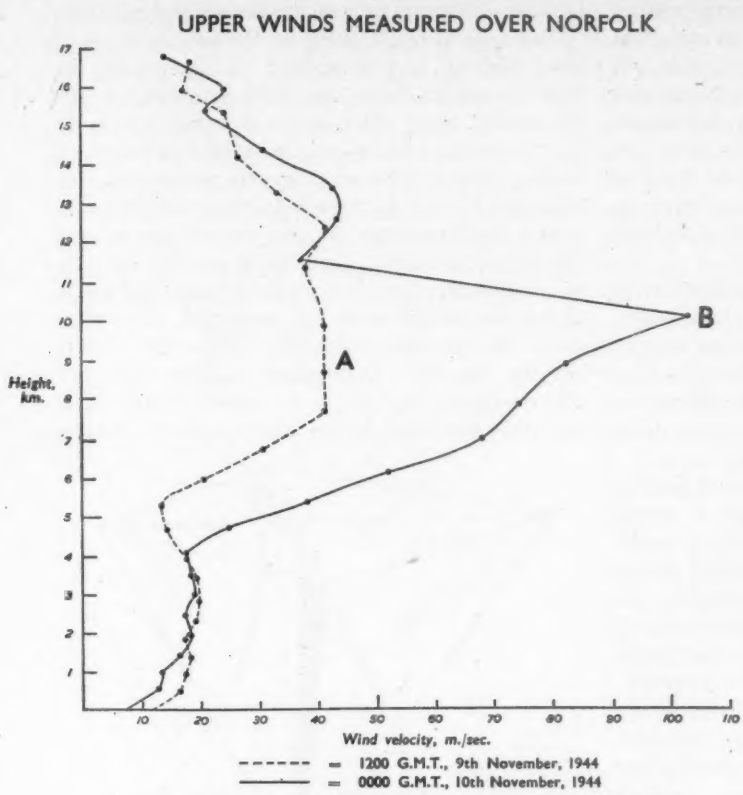


FIGURE 3 – *Wind structure at (A) noon and (B) midnight on 9th November, 1944.*

winds are much stronger than those of summer, the former averaging 37 metres per second and the latter only 12 metres per second. The greatest velocity observed during the period was 66 metres per second (147 miles per hour).

In addition to knowing the movement of the air aloft, the meteorologist also needs to know its physical conditions, i.e. its pressure, temperature, and humidity. This information is obtained by means of the radio sonde—possibly the most interesting of all meteorological instruments. Not only does it measure the properties just mentioned, but it automatically sends out radio signals telling the observer on the ground the values of these three quantities.

A radio sonde consists essentially of two main parts. First there are the meteorologically sensitive elements—one responding to the pressure, another to the temperature, and a third to the humidity of the atmosphere. The second part is the radio transmitter, together with mechanism for enabling variations in the meteorological components to impart corresponding variations in the radio transmissions.

Most radio sondes employ one of two principles. The first is the chronometric principle, which may be illustrated by reference to figure 4. Imagine an arm to rotate uniformly with a fixed contact at some point on the circumference; then contact will occur at regular intervals equal to the period of rotation of the arm. If now another contact is introduced, the position of which on the circumference is varied by a pressure-sensitive element, the time-interval between the fixed contact and the movable contact gives a measure of the pressure. If the circumference is divided into three sectors, one sector can be allotted to pressure variations (P), the second to temperature variations (T), and the third to humidity variations (U). Measurements of the pressure, temperature, and humidity can thus be obtained by observing the sequence of time-intervals. All that is necessary is to receive the transmitted radio message on a chronograph and to read off the time-intervals, which can be interpreted from the calibration chart for that particular transmitter. This principle has been adopted in the Canadian, Indian, and French instruments.

The other main principle employed in radio sonde design is that of causing the meteorological element to vary the frequency of the radio transmission. The frequency of an electrical circuit is determined by its capacitance, resistance, and inductance: the frequency can therefore be varied by changing any of these three quantities. In the Finnish instrument the capacitance of the circuit is varied; the American instrument varies the resistance; while the British instrument, of which the prototype was designed by the National Physical Laboratory, varies the inductance. There is, however, a minor difference between these instruments. Whereas the Finnish radio sonde varies the fundamental frequency of its transmissions, the other instruments produce variations in an audio-frequency modulation superimposed on the fundamental wave.

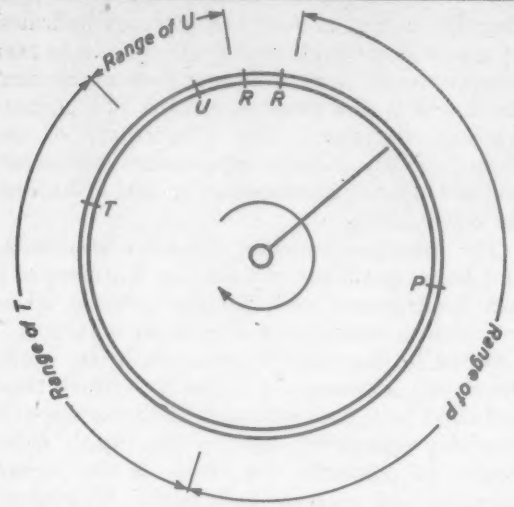


FIGURE 4 – *Chronometric principle employed in certain radio sondes.*

In order to illustrate how these principles are applied in practice, very brief descriptions will be given of the Canadian, Finnish, British, and American instruments. The first employs the chronometric principle; the other three depend upon frequency variation.

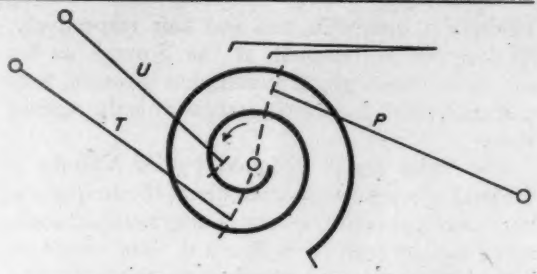


FIGURE 5 – *Chronometric unit of Canadian radio sonde.*

The central component of the Canadian instrument is a brass strip bent into the form of an equiangular spiral, which is rotated at a steady rate by a small electric motor (figure 5). The three meteorological elements are arranged around it, and each moves an arm carrying a fine contact wire at its end. The deflection of any of these arms from its normal position varies the time at which the contact occurs, and the latter can thus be made to indicate the former. Two fixed contacts placed close together are used to distinguish the reference point from the variable contacts.

The meteorological element for indicating pressure changes consists of an aneroid capsule, while for the temperature and humidity variations use is

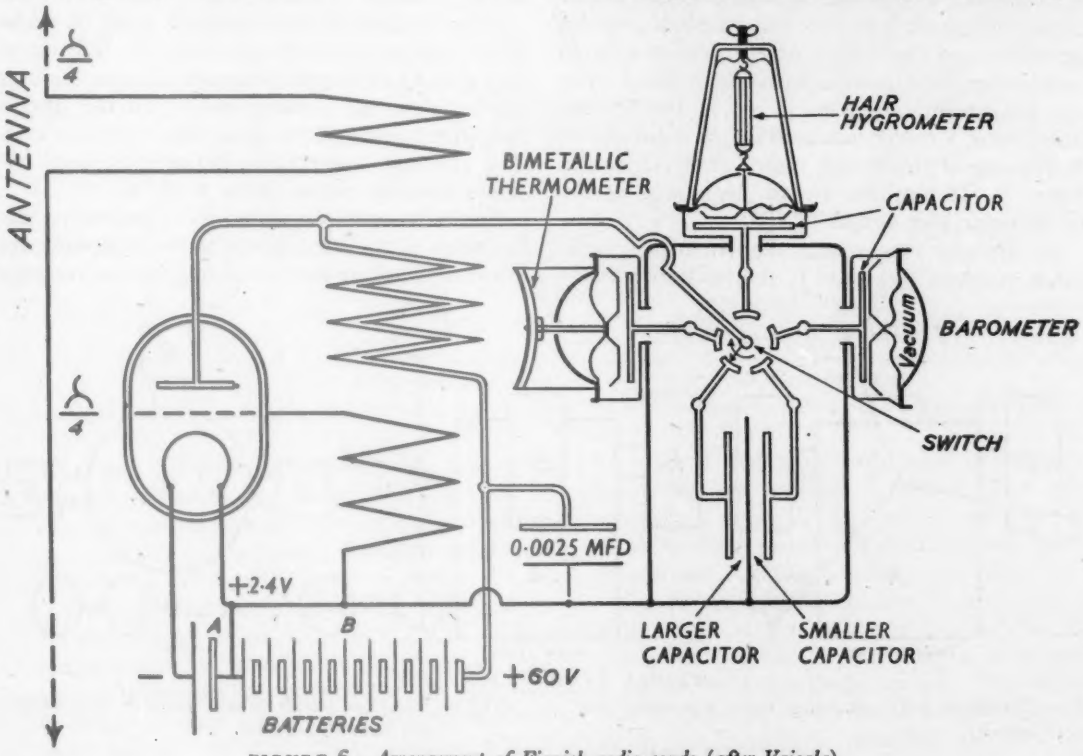


FIGURE 6 – *Arrangement of Finnish radio sonde (after Vaisala).*

made of a bimetallic coil and hair respectively. The record is received at the ground on an ingenious chronograph which plots pressure, temperature, and humidity graphs directly against time.

The radio sonde designed by Dr Vaisala of Finland is an excellent example of the frequency-variation type of instrument. The general arrangement can be seen from figure 6. The meteorological elements are similar to those in the Canadian instrument, but in this case each carries one plate of a capacitor, the movement of which varies the capacitance, and hence the frequency, of the transmitting circuit. A windmill operates a rotary switch which connects each of the variable capacitors into the circuit in turn. There are also two fixed capacitors as reference marks. Incidentally, the Vaisala instrument is of very neat and compact design.

The British radio sonde resembles the Finnish instrument in general arrangement, but differs in two main respects. In the first place, each meteorological element is made to vary the inductance of an iron-cored winding, by moving an armature towards or away from the U-shaped iron core. The second major difference lies in the fact that in the British instrument the fundamental frequency of the transmissions remains constant, and the variations are produced in an audio-frequency modulation superimposed upon the fundamental frequency. As in the Finnish instrument, a rotary windmill switch is employed. A drawing of the British radio sonde is given in figure 7. It is about 19 cm. high and 14 cm. in diameter, and weighs 1½ kg.

As already mentioned, the American radio sonde employs variations in the resistance of the electrical circuit. Pressure variations are indicated by a pair of aneroid capsules, which move an arm over a series of contacts. The temperature element consists of a fine glass tube filled with a non-freezing electrolyte. The conductivity of the electrolyte has a large temperature coefficient, and its resistance can therefore be used to indicate the temperature.

The American humidity element is also novel, and makes use of the variations in resistance of a film impregnated with lithium chloride when subjected to atmospheres of different humidity.

Before leaving these instruments, a few words upon their accuracy are called for. Much time and effort have been expended in discovering and removing sources of error in the British radio sonde. In particular the effects of the intense incoming and outgoing radiation at high levels have been investigated. These affect not only the meteorological elements but also parts of the electrical circuit. It is believed that the British radio sonde now gives temperature readings with an accuracy of about $\pm 0{\cdot}5^\circ$ C. An accuracy of one millibar is aimed at in the pressure measurements. Although this represents only a tenth of one per cent. at sea-level, it becomes one per cent. at a height of about 15 km.

None of the humidity elements used on radio sondes can be regarded as satisfactory. The lag in response of hair becomes excessive at temperatures much below the freezing point. In the British instrument goldbeater's skin is now used, but even this, although appreciably better than hair, becomes virtually useless below -25° C.

The only satisfactory method of measuring the humidity of the atmosphere at low temperatures is by means of the frost-point hygrometer recently

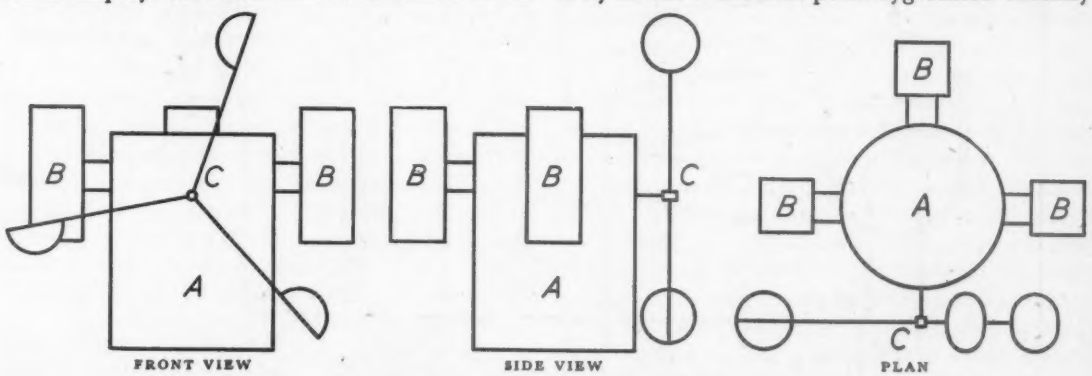


FIGURE 7 – *British radio sonde.*

A = Cylindrical body containing radio transmitter and batteries.

BBB = Radiation shields around pressure, temperature, and humidity elements.

C = Windmill operating rotary switch.

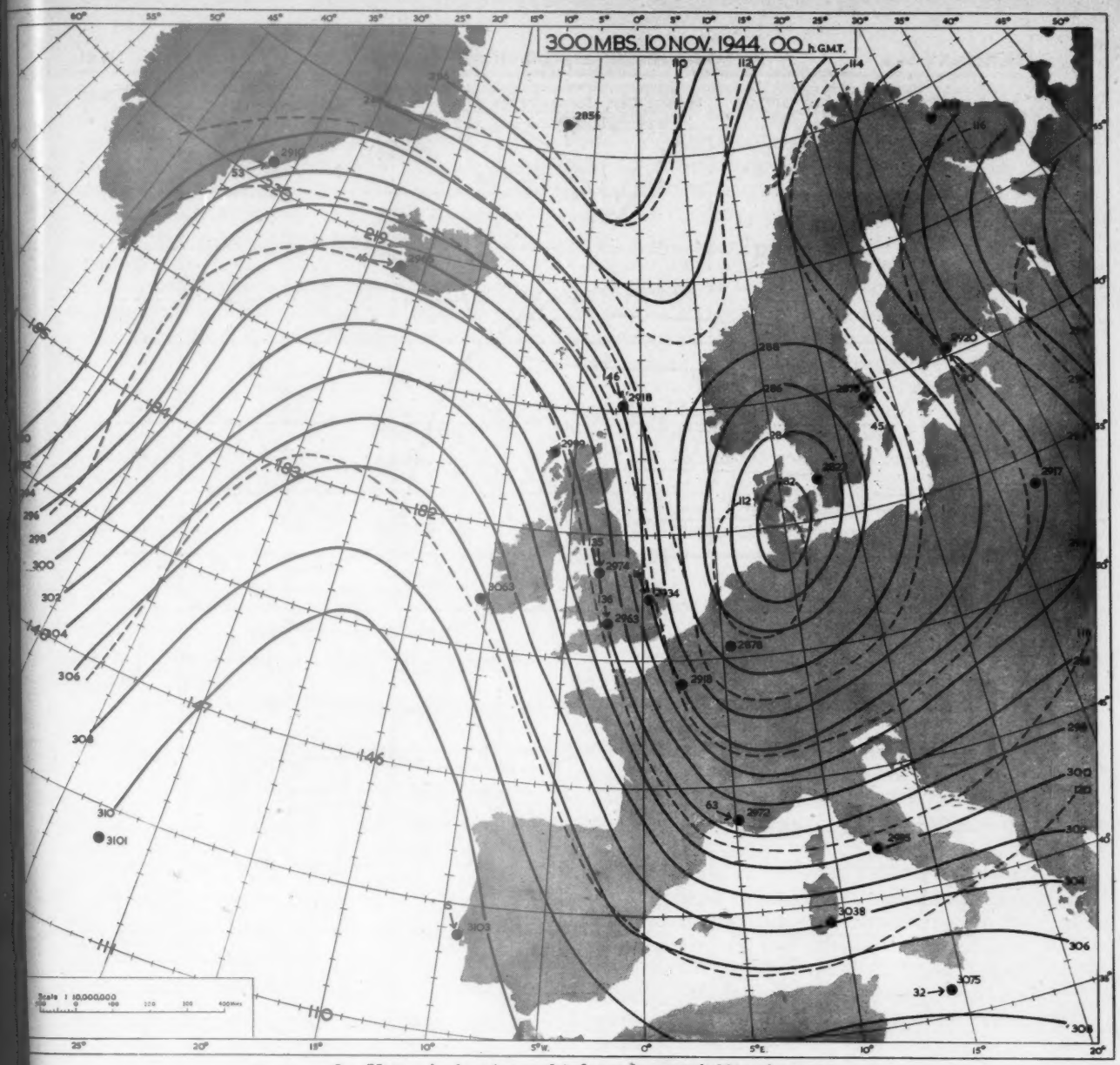


FIGURE 8 – *Upper-air chart* (300 *mb.*) *for* 00 *h. on* 10*th November*, 1944.

For explanation see pages 135–6. The arrows and the (smaller) figures adjacent to them represent wind direction and velocity.

developed by Dobson and Brewer. Up to the present, however, the design has not been developed to a stage in which it can be used without an operator, and it cannot therefore yet be employed in a radio sonde.

The temperature encountered in the stratosphere may be as low as — 80° C, and at these temperatures the maximum quantities of water vapour that can be present are so excessively minute that their quantitative determination by most methods becomes impracticable. The depression of the hoar-frost point below the air temperature is, however, a quantity that remains reasonably large. Thus at a temperature of — 50° C the depression of the hoar-frost point for 50 per cent. relative humidity is about 5° C.

The principle of the Dobson-Brewer hygrometer is the same as that of the well-known Regnault dew-point hygrometer, in which a metal surface is cooled until dew forms upon it. The construction of Dobson's instrument is shown in figure 10. A copper thimble is mounted above a Dewar

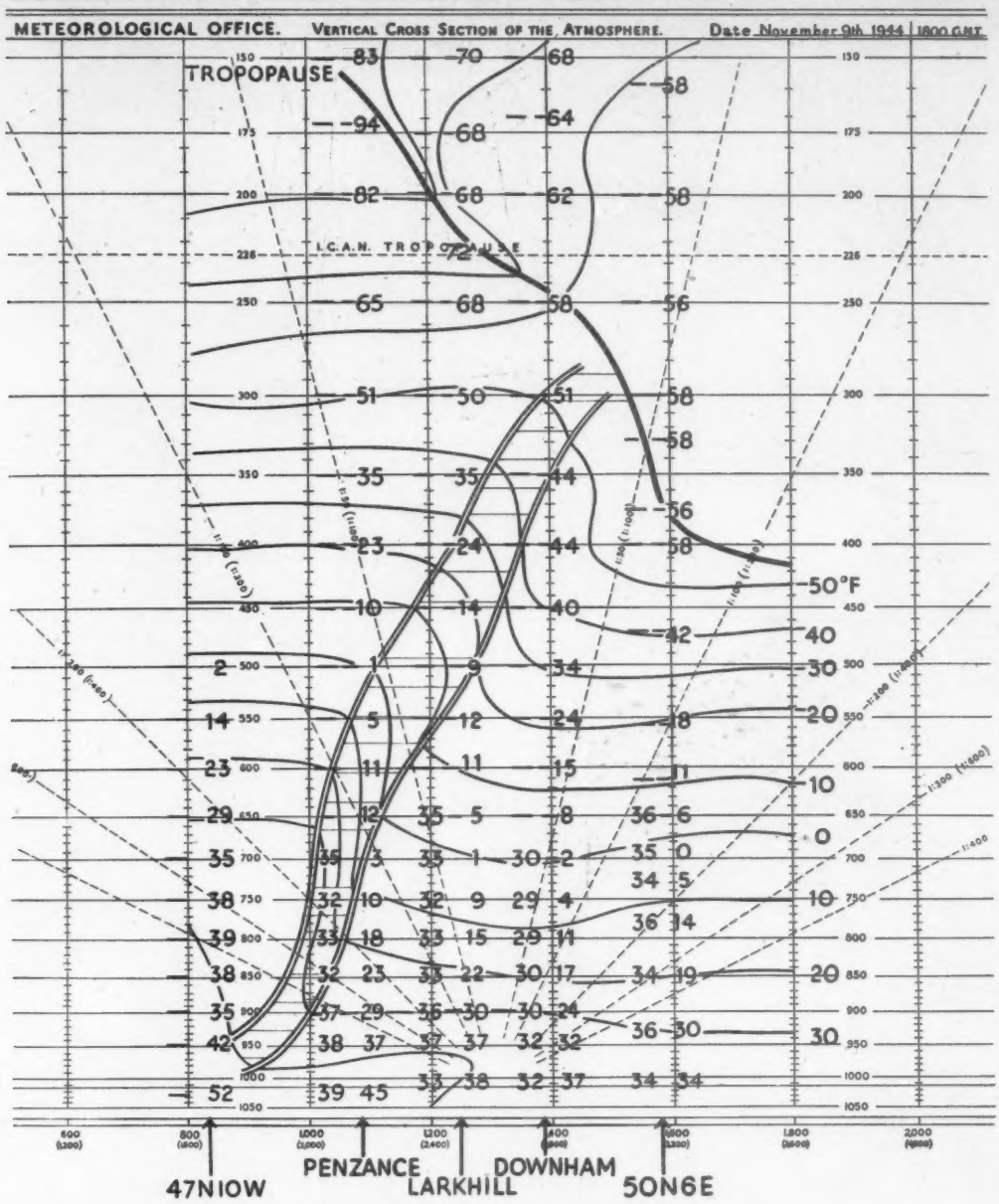


FIGURE 9 – *Vertical section of atmosphere for* 18 *h. on* 9*th November,* 1944.

flask containing petrol cooled by adding solid carbon dioxide. By means of a hand-operated pump the cold petrol can be made to impinge against the lower side of the thimble, on the upper face of which a deposit of hoar frost eventually forms. The temperature at which this occurs is indicated by an electrical thermometer embedded in the thimble. The formation of the deposit is detected by the aid of a photoelectric cell, which is found to be substantially more sensitive than visual observation. A beam of light is directed obliquely on to the upper face of the thimble, and the reflected beam is absorbed by a light trap. With the formation of a deposit of hoar frost on

the thimble face, some of the light is scattered and is focused on to the photocell. In practice the temperature of the thimble is adjusted to give a steady reading of the photocell microammeter, showing that the hoar-frost deposit is neither growing nor evaporating. A small heating coil around the thimble facilitates the control of its temperature.

Mounted in an aircraft, this instrument has given excellent results in the hands of Mr Brewer, who has made many ascents into the stratosphere.

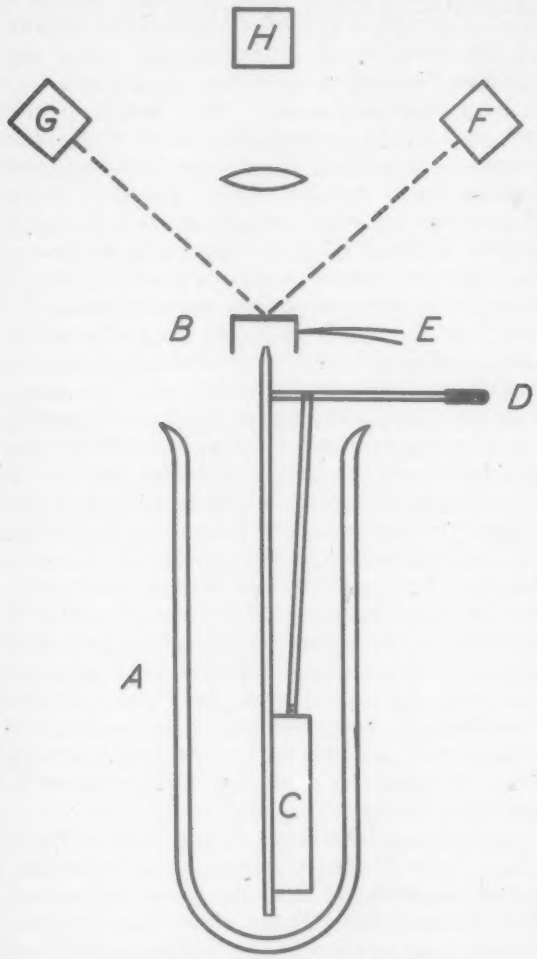


FIGURE 10 – *Dobson-Brewer hygrometer.*

A = Dewar flask containing petrol cooled by solid carbon dioxide.
B = Thimble.
C = Pump operated by handle D.
E = Electrical thermometer embedded in thimble.
F = Light source.
G = Light trap.
H = Photocell.

The most important result is the discovery of the fact that the air in the stratosphere is exceptionally dry. Up to the base of the stratosphere the relative humidity generally lies between, say, 30 and 100 per cent., but on entering the stratosphere the humidity falls rapidly, until at a distance of about 2 km. within the stratosphere the value is in the region of 1 per cent.

The height at which the stratosphere begins varies with the meteorological situation. In the latitudes of the British Isles the average height is about 11 km., but it may lie between about 8 km. and 16 km. The very low humidity mentioned above has been observed on occasions when the base of the stratosphere was at about 10 km. It is not yet known whether such low humidities occur when the base of the stratosphere is at greater heights. The low humidity is presumably due to subsidence of the air from the stratosphere in equatorial regions, in which case the lowest humidities would be expected only when the base of the stratosphere is relatively low in temperate latitudes.

In passing, this recent knowledge about the humidity in the stratosphere throws light upon a phenomenon which was observed in the early stages of the war. It was discovered that the 'vapour trails,' which were such a conspicuous feature of the sky around the time of the Battle of Britain, ceased to be formed if the aeroplane climbed into the stratosphere. It would perhaps be more correct to say that only short and faint trails were produced instead of the long and dense trails at lower levels. These vapour trails are formed by the condensation of the moisture in the exhaust gases from the aeroplane engine. It is now clear that the failure of dense trails to form in the stratosphere is due to the fact that the very low humidity causes the trail to evaporate almost as fast as it is formed.

It will have been noted that the aim of all the new observing techniques described above is to secure additional information about the upper atmosphere. It is now proposed to indicate briefly how the information so obtained is used.

The primary value of upper-air observations is for the construction of charts for the upper levels of the atmosphere, corresponding to the well-known synoptic charts for sea-level. In the latter, isobars are drawn for this standard level. In the case of the upper-air charts, however, the practice evolved in Britain is to draw isopleths showing the height of the surface of a selected value of pressure. The resulting charts are very similar in

appearance to ordinary synoptic charts, a depression, for example, being represented by a series of concentric closed curves. A series of charts is drawn for the pressure levels of 1,000, 700, 500, and 300 mb. These correspond roughly to heights above sea-level of zero, 11,000, 18,000, and 30,000 ft. respectively.

The 1,000 mb. surface chart is first computed from the sea-level pressure readings. The thicknesses of the successive layers, 1,000–700 mb., 700–500 mb., and 500–300 mb., are then calculated from the upper-air temperature and humidity observations given by the radio sonde or aeroplane ascents. By adding these thicknesses successively to the 1,000 mb. chart, a series of contour charts is obtained for each of the pressure levels—700 mb., 500 mb., and 300 mb. Upper-air observations are made and charts are drawn every six hours, giving a sequence of charts which show the tendencies of temperature, thickness, and height of isobaric surfaces. Figure 8 shows the 300 mb. chart for the occasion referred to earlier, when a wind velocity of over 200 m.p.h. was recorded (see figure 3). These upper-air charts enable direct forecasts to be made of the wind, cloud, and other conditions in the upper atmosphere for aviation purposes.

The upper-air data are also used for drawing vertical sections of the atmosphere. Figure 9 is such a diagram and refers to the same occasion as figure 8.

In this type of diagram horizontal distances are plotted as abscissae, the position of each observing station being shown by its name or its geographical co-ordinates. The vertical scale is height, but is magnified two hundred times compared with the horizontal scale. Above each observing position are plotted two columns of figures. The right-hand column is the observed air temperature at successive heights (or pressure-levels), which enable the isotherms to be drawn. These are roughly horizontal in the right-hand portion of figure 9 but turn sharply upwards at the 'cold front' shown by the two steep double lines towards the left of the figure. Although a 'front' is usually spoken of as if it were a line, in practice the discontinuity is not sudden but is spread over a zone perhaps a hundred miles wide.

The left-hand column of figures entered above each observing position in figure 9 is the 'wet-bulb potential temperature.' This is a conservative property throughout any particular air mass, and it is therefore extremely valuable in identifying and locating the limits of air masses. The constancy of the wet-bulb potential temperature, both vertically and horizontally, to the right of the front in figure 9 will be noted. The height of the base of the stratosphere (i.e. the tropopause) is indicated by the heavy line towards the top of the diagram. The rapid change of height which occurs in the vicinity of the 'front' is noteworthy.

Figure 9 has been discussed at some length because it affords a good illustration of the detailed study which can be made of the atmosphere as a result of the new observing techniques.

These two types of upper-air chart (figures 8 and 9) provide a vivid three-dimensional picture of the structure of the atmosphere and of the air-mass movements which are taking place.

No account of the recent study of atmospheric processes would be complete without a reference to the work which is being done upon radiation equilibrium in the atmosphere. There are many facts about the upper atmosphere which cannot yet be explained. For example, it is not known why the temperature of the stratosphere is 50° C lower over the equator than over the poles, and why it varies considerably with time. The radiation conditions in the stratosphere are governed largely by such minor constituents as water vapour, ozone, and carbon dioxide and possibly other polyatomic gases. The solution of the problems just mentioned therefore requires a knowledge of the gases comprising the high atmosphere, the density of these gases at various levels, and their absorption coefficients for various wavelengths. Full understanding of the problems also involves knowing how such gases are formed and decomposed. These investigations clearly represent long-term fundamental research of a complex character, but solutions to them are essential for a rational understanding of the atmosphere and its ways, and they are being actively pursued under the guidance of the Gassiot Committee of the Royal Society.

In the foregoing review we have discussed three phases in the history of meteorology. In the first phase, the study of the subject was attempted from observations made at a single place. A great advance was made when it became possible to collect regular observations over an extended area and led to phase two. The third phase is characterized by a three-dimensional approach to the subject. The observational instruments necessary for such an approach have recently been developed. The third phase, however, is only just beginning, and it would be rash to predict how rapid further progress is likely to be.

Tycho Brahe, 1546–1601

HERBERT DINGLE

The importance of precise observation in the formulation of theories is now so universally recognized that it is difficult to appreciate that it has not always been thus. Tycho Brahe's realization of the fact enabled him to accumulate the data essential for Kepler's expression of the planetary laws, an event which profoundly affected the future development of astronomy. His principles are, however, fundamental to the scientific method of today, and his teaching ultimately reached far beyond the astronomical field in which it was first applied.

The period known as the Renaissance was a critical epoch in many departments of thought and knowledge, and in none more so than in astronomy. The importance of this fact is greater than appears at first, for astronomy was so interwoven with the general texture of medieval thought that its reformation entailed a new outlook on life and on the world as a whole. Fortunately its development at this time is easy to trace and understand, at least in its broad outlines, for it was mainly the work of four men. The essential change of viewpoint was introduced by Copernicus, but Copernicus did little to take advantage of the opportunity he had created. He took the medieval vision with him to the modern viewpoint and saw the celestial spheres and the Ptolemaic deferents and epicycles enveloping the sun instead of the earth. Kepler was the first to show what possibilities lay in the Copernican reform, and his laws of planetary motion, in which spheres and perfect circular motion were finally abandoned, contained in essence the solution of the whole problem of medieval astronomy. Kepler's work would have closed the study of astronomy, except for a few minor adjustments, had not Galileo with his new mechanics and 'optic tube' given the subject a new life and opened up the limitless fields of inquiry which we are still exploring. To these three men we owe everything which we now possess in theoretical astronomy, but their work would have been essentially incomplete or impossible without that of a fourth. It is to Tycho Brahe that Kepler was indebted for the observations which enabled him to express the true planetary laws in Copernican terms, and this was not a mere accidental debt. The work of Tycho represented a new outlook, a change as radical in its way as that of Copernicus, for, surprising as it may seem now, the idea that before describing phenomena one should know as accurately as possible what those phenomena were, was almost unthought of in the sixteenth century. Tycho was thoroughly modern, and in his day almost unique, in realizing the value of precision in measurement, and Dreyer, his excellent modern biographer, opines that his accuracy 'but for the invention of the telescope could hardly have been much exceeded by his successors.' Certainly without Tycho's work there would have been no Kepler's laws, and possibly Newton would have been unable to formulate his law of gravitation.

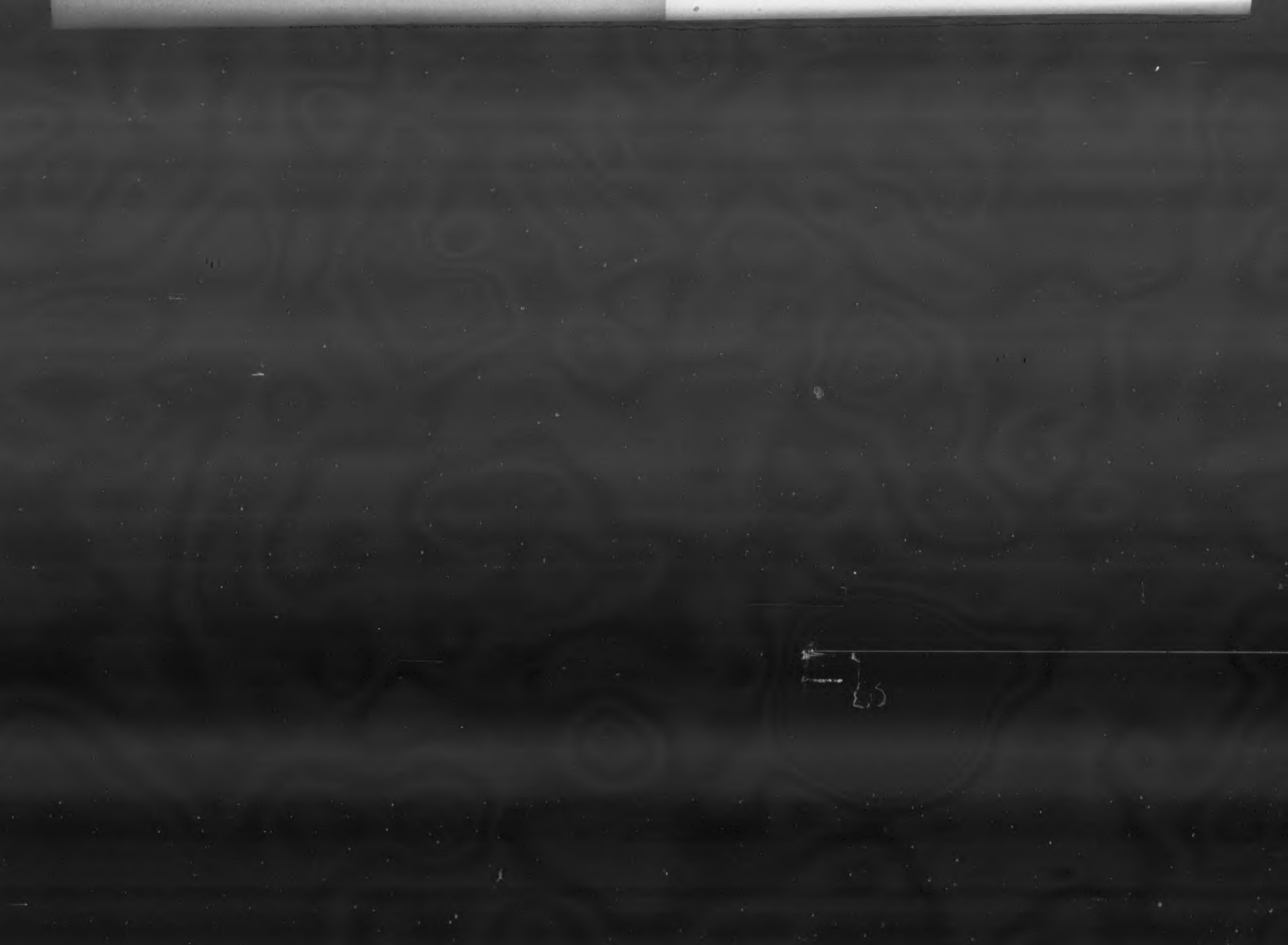
Tycho Brahe (or Tyge Brahe, to give him his Danish name) was born at Knudstrup on 14th December, 1546. He was the second child and eldest son of Otto Brahe, a privy councillor and member of an ancient noble Danish family, and his wife, Beate Bille. He was brought up by his uncle, Jörgen Brahe, who, being childless, had, partly by force and partly by persuasion, succeeded in obtaining charge of him. After preliminary education under a tutor he went, at the age of 12, to the University of Copenhagen, and studied rhetorics and philosophy with a view to becoming a statesman. A partial eclipse of the sun on 21st August, 1560, however, profoundly impressed him, and he thought it 'as something divine that men could know the motions of the stars so accurately that they could long before foretell their places and relative positions.' He immediately began to study the subject, and bought a volume of the works of Ptolemy which seems to have absorbed his interest during the remainder of his three years' study at Copenhagen. This aberration somewhat disturbed his uncle, who, on sending him to a foreign university according to custom (Leipzig was chosen for Tycho), sent with him as tutor a young man, Anders Vedel, whose duty it was to see that his studies were such as befitted a nobleman. Vedel—who subsequently attained distinction as a historian and remained a lifelong friend of Tycho—

tried conscientiously to fulfil his obligations, and at first Tycho had to study astronomy and mathematics while Vedel was asleep. After some remonstrances, however, Vedel was forced to acknowledge that Tycho was born for astronomy and for nothing else, and a tacit working arrangement seems to have established itself. When only 16 years of age, says Dreyer, 'his eyes were opened to the great fact, which seems to us so simple to grasp, but which had escaped the attention of all European astronomers before him, that only through a steadily pursued course of observations would it be possible to obtain a better insight into the motions of the planets, and decide which system of the world was the true one.' His first observation was of an approaching conjunction of Jupiter and Saturn, made with a pair of ordinary compasses on 17th August, 1563, but he soon set about acquiring a better instrument. In the following year he secured a 'radius'—two graduated rods of which the longer bisected the shorter at right angles and could move in its own direction so that, sights being fixed at each end of the shorter rod and at one end of the longer, a position could be found in which the eye, placed at the last-named sight, could see through the others two stars whose angular separation was to be learned. This did not satisfy him, but, being unable to get money from Vedel for a still better instrument, he made observational history by constructing a table of corrections to its readings.

Tycho's uncle died shortly after his return to Denmark, and, his relatives looking with disfavour on his odd interests, he soon left again for Wittenberg and later Rostock, where, in a famous duel, he lost his nose and made for himself an artificial one of gold and silver. In the meantime, however, his astronomical pursuits were not entirely discountenanced at home, and on 14th May, 1568, King Frederick II of Denmark granted him the next vacant canonry—a sinecure which would afford him means of continuing his astronomical work in his native country. Nevertheless, more than two years elapsed before he returned—years in which at Augsburg he constructed, with his friends the brothers Hainzel, a quadrant with a radius of 14 cubits (about 19 ft.), a sextant, and a celestial globe 5 ft. in diameter. For some reason he did not immediately continue this work in Denmark but turned his attention to alchemy, until, on leaving his laboratory on 11th November, 1572, he noticed an extremely bright star in Cassiopeia where, as he well knew, no such star was wont to appear. Doubting his senses, he appealed to some neighbouring peasants for confirmation, and when the reality of the star could no longer be questioned he at once proceeded to measure its position. From then onwards Tycho never allowed his interest in astronomy to lapse. He constructed instruments, introduced devices to make them foolproof, determined their errors, and gave the limits of accuracy of the results—a procedure in observation which was unique in his day. Its importance in this case was that Tycho established beyond question that the parallax of the star was too small for it to be as near as the planets, and it must therefore belong to the sphere of the stars whose immutability had been a cardinal principle of astronomy from the earliest days. Nothing but observations of which the degree of exactitude was high and was known could have placed this momentous fact beyond question. Later, when a comet appeared in 1577, he was able to show by precise measurements that it must have passed through the material of the spheres, if these existed, and another ancient illusion was shattered.

After completing his work on the new star, Tycho travelled extensively in central Europe, finding in particular a kindred spirit in the Landgrave Wilhelm of Cassel, an astronomer of no mean ability. It was through the Landgrave that King Frederick realised fully what a remarkable subject he possessed, and when Tycho, during a short visit to his native land in 1576, was planning to settle permanently in Basle, the King made him such a munificent offer that he altered his plans and decided to remain. The chief part of the gift was the island of Hveen 'with all our and the Crown's tenants and servants who thereon live, with all rent and duty which comes from that, and is given to us and to the Crown, to have, enjoy, use and hold, quit and free, without any rent, all the days of his life.' There were also sums of money for building an observatory, and various sources of income involving little more than nominal duties. The offer was too good to be refused, and at the end of May Tycho began to build the observatory which was to be his home for more than twenty years and at which the greater part of his work was done.

Space prevents a detailed description of what must have been a most palatial observatory even by modern standards. The illustrations give a general idea of the layout. The main building, known as Uraniborg, was nearly in the centre of the island and was built in the Gothic Renaissance style then becoming popular. It was at first the only



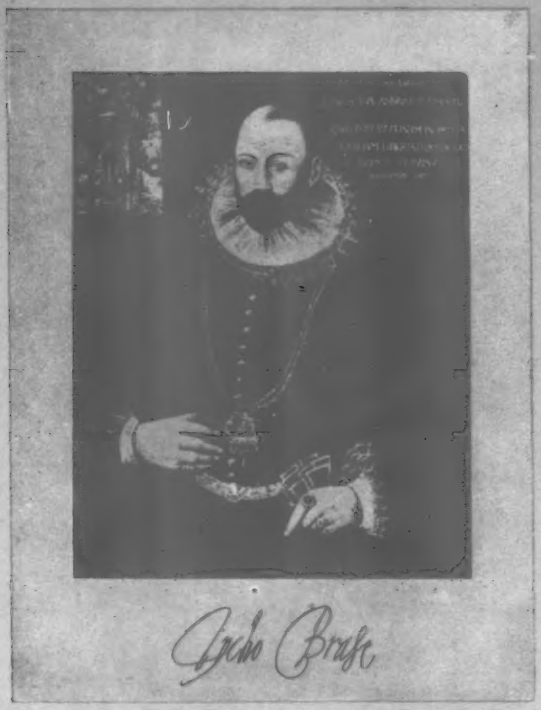


FIGURE 1 – *Tycho Brahe, from a portrait at the Royal Observatory, Edinburgh.*

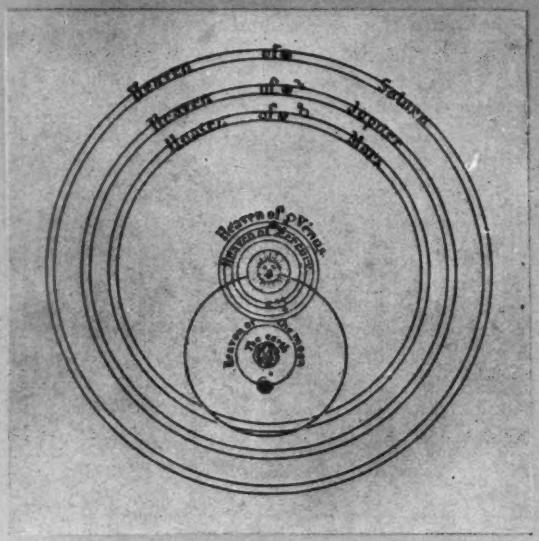


FIGURE 2 – *Tycho Brahe's astronomical system. The earth was stationary, and the moon and sun travelled round it. The other planets travelled round the sun and therefore with it circled the earth.*

Illustrations from Tycho Brahe, *by J. L. E. Dreyer, published by A. & C. Black Ltd.*

astronomical building, but in 1584 a second observatory was erected to the south, known as Stierneborg. To this island astronomers from all over Europe came to work with Tycho, and the work done there is the basis of modern astronomy. Tycho's innovations consisted first in the great size of his instruments; secondly in his improved method of graduation—he was the first astronomer to use the method of *transversals* in which the main graduations were made alternately on each of a pair of parallel arcs, successive marks being joined diagonally so as to form a zigzag pattern (see, for example, figure 4); thirdly in a greatly improved method of constructing and arranging his 'sights'; and, finally, in the practice already mentioned of determining as precisely as possible the errors of his instruments. His most outstanding contributions, in addition to the destructive ones already mentioned (to which may be added the final disproof of a long-maintained belief in a false movement of the stars known as *trepidation*), included far more accurate observations of the positions of the heavenly bodies than any previously made, the first observations of the effect of atmospheric refraction on apparent positions, and the discovery of the third and fourth inequalities (known respectively as the *variation* and *annual equation*) in the moon's motion as well as the fluctuation in the inclination of the moon's orbit to the ecliptic. Tycho differed from all his predecessors in making his observations in a systematic manner. Whereas it had been customary to make occasional observations of the positions of the planets, Tycho observed them regularly and systematically before and after opposition. This systematic observation, combined with the care and accuracy with which the observations were made, enabled Kepler to deduce his three laws of planetary motion and so to lay the foundation of celestial mechanics. These laws could never have been deduced from a few observations made near opposition.

In general, Tycho was less concerned with the interpretation of his observations than with their acquisition; it was left to Kepler to show what an abundance of knowledge they enshrined. He was anything but indifferent, however, to the great question of the day—the decision between the

FIGURE 3 – *Uraniborg from the east The N.–S. distance is about* 100 *ft. and the greatest height* 62 *ft.*

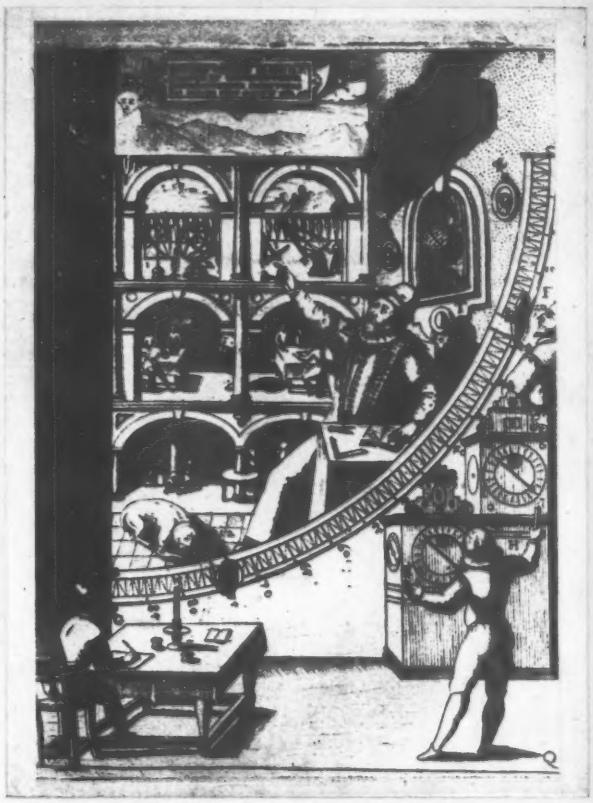


FIGURE 4 – *The great mural quadrant at Uraniborg. This instrument consisted of a brass arc of* 6¾ *ft. radius, divided by transversals and screwed to the wall, on which were painted a portrait of Tycho and some of the wonders of Uraniborg.*

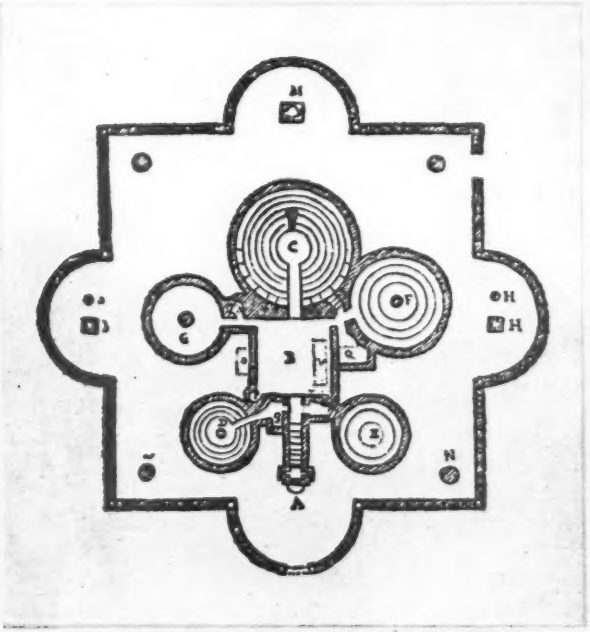


FIGURE 5 – *Plan of Stierneborg. C, D, E, F, and G are subterranean rooms with only the roofs above ground, to protect the instruments from the wind. O and Q are bedrooms for Tycho and an assistant, and S is an unfinished subterranean passage towards Uraniborg.*

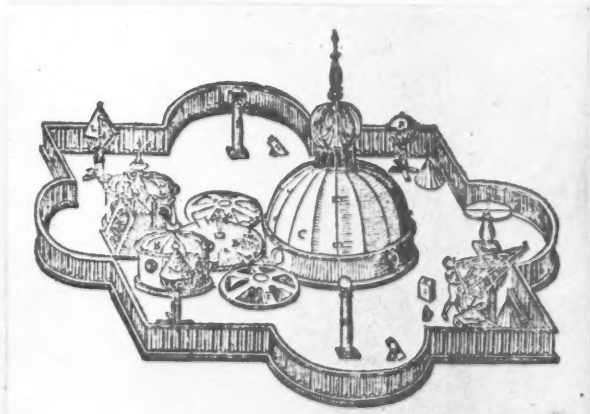


FIGURE 6 – *Stierneborg from the west. This and figures* 3 *and* 5 *are copied from Tycho's book,* Astronomiae Instauratae Mechanica (1598).

Ptolemaic and Copernican views of the universe—and it is possible that he thought more highly of his own solution of this problem than of any of his other achievements. This was a rather strange compromise between the two alternatives: the planets, excluding the earth, travelled round the sun in Copernican fashion, but the whole system, thus formed, itself moved round the stationary earth. So far as the solar system is concerned this is mathematically equivalent to the Copernican conception, but it fails to account for the aberration of light and the annual parallax of the stars. These phenomena, however, were not known to Tycho, and he accordingly believed that he had found the true answer to the central problem of astronomy; his last request to Kepler, in fact, was that he would interpret the observations according to the Tychonic and not the Copernican system. This is by no means a unique example of a creator proving himself an indifferent critic of his own achievements.

The great work at Uraniborg came to a melancholy end in 1597. On the death of King Frederick in 1588 his son Christian, then only 11 years of age, came largely under the control of certain nobles, some of whom were inimical to Tycho. This circumstance—together, it must be admitted, with Tycho's somewhat arbitrary behaviour—led to an increasing degree of estrangement, which culminated in Tycho's position at Hveen finally becoming untenable. In March or April 1597 he left his historic observatory for ever. The instruments were gradually dismantled and some of them sent to him in Bohemia, but their great work was done. They were all too jealously guarded after Tycho's death by Curtius, who would not allow even Kepler to use them, and ultimately all were destroyed by war or by fire. Of Uraniborg scarcely a trace remains. When Gassendi in 1647 visited Hveen in search of memorials of Tycho his findings were summed up in the simple phrase: 'There is in the island a field where Uraniborg was.'

On leaving Hveen Tycho, after some wandering, sought and obtained the patronage of the Emperor Rudolph. He was granted the Castle of Benatky, on the river Yser, about twenty-two miles north-east of Prague, and here, with reduced equipment, he resumed his observations. Little time was left, however, and the work in Bohemia is chiefly notable for the collaboration of Tycho and Kepler which produced such momentous results. Tycho's health gradually failed, and he died on 24th October, 1601.

As a man Tycho was not altogether lovable or admirable. He was overbearing, and failed to carry out the extremely light obligations which the generosity of the King had placed on him in return for his privileges. Of his utterly selfless devotion to astronomy, however, there is no doubt, and it must be recorded in his favour that in an unfortunate dispute with Kepler, in general a far more noble-minded man, it is Tycho who appears in the more favourable light. Also, while at Hveen it was his habit to give away medicines which, through his lifelong love of alchemy, he made a practice of preparing and in which he placed considerable trust. Tycho was fond of mystery and display, and his observatory at Uraniborg abounded in mechanical devices and imperceptible means of communication with which he liked to mystify his visitors. He wrote tolerable verses, some of which, as well as paintings, adorned the walls of his observatory. A typical example of the ornate character of the building was the ceiling and walls of the study at Stierneborg, which showed the Tychonic system of the world and the portraits of eight astronomers, ending with Tycho and 'Tychonides,' a successor yet unborn. In the inscriptions underneath, Tycho leaves his own work to the judgment of posterity, but the hope is expressed that Tychonides might be worthy of his great ancestor. Attached to the observatory was a dwarf called Jep, whom Tycho used to feed with an occasional morsel at table, like a dog. Jep was supposed to be clairvoyant and to have made some remarkable prophecies. Tycho was a firm believer in astrology and gave as rational a defence of the doctrine as was perhaps possible. In this, however, he was by no means abnormal, since astrology was a respectable university subject in his day, and only very exceptional men like Copernicus seem to have ignored it; open disbelief was almost out of the question. In short, Tycho was a typical child of the Renaissance—one of those strange mixtures of the medieval and the modern which are so baffling to us today.

Enough has been said, however, to indicate the indispensable part which Tycho's work played in the development of astronomy. In a sense he was more of an originator than most of the deeper thinkers of his time, for while the perception of the necessity for accurate and systematic observation called for a less powerful intellect than the rational organization of the universe, it was much less conformable with the spirit of the time.

The measurement of coloured light

JOHN W. T. WALSH

The comparison of light intensities when the sources are of the same colour is susceptible of high accuracy, but for experimental and commercial purposes it is often necessary to compare sources which differ widely in colour. The problem then becomes much more difficult owing to differences in the reaction of observers, particularly when the light is dim. In this article the accuracy and limitations of modern methods of colour photometry are surveyed.

The measurement of light is usually carried out by means of a photometer, in which two illuminated white surfaces are compared by an observer, who adjusts the illumination of one or both until he judges that they are equally bright. Any marked difference of colour between the lights illuminating the two surfaces makes this judgment more difficult and uncertain; nevertheless the observer can always find a condition such that surface *A* is undoubtedly brighter than surface *B* and another in which *B* is certainly brighter than *A*. The methods used in heterochromatic photometry have been devised with the object of reducing as far as possible the gap between these two conditions. The fact that this gap need not exceed two or three parts in a thousand when there is no colour difference gives some indication of the target.

Unfortunately, in addition to the uncertainty which a colour difference produces in a single observer's judgment, there may also be a not inconsiderable spread in the results obtained by different observers. This results from the variations which are known to exist in the colour response even of normal-sighted individuals. For instance, the two coloured surfaces shown in figure 1 may be judged equal in brightness by one observer with normal vision, whereas another may well require the brightness of one or other surface to be increased by as much as 30 per cent. before he will assess them as equal.

In order that measurements of lights of different colours may be consistent, it has been agreed internationally that the methods used in heterochromatic photometry shall, in addition to reducing the uncertainty of a measurement, also make it agree with the results which would be obtained by an observer having a certain specified 'average' response to colour.

THE FLICKER PHOTOMETER

In the ordinary photometer-head, used when colour differences are negligible or at any rate quite small, the two surfaces are seen side by side. When there is a marked colour difference, however, an entirely different method of making the comparison is frequently employed. The two surfaces are rapidly alternated before the observer's eye so that he sees first one and then the other, and as the speed is raised the field of view presents a flickering appearance. The flicker diminishes and finally disappears altogether as the rate of alternation of the surfaces is increased. This rate is under the observer's control, and he is required to adjust the illumination of one or both of the surfaces until the speed at which flicker just disappears is a minimum. If there is no colour difference between the lights, the minimum rate at which flicker disappears is comparatively low, namely about ten to fifteen alternations per second. A colour difference, however, causes perceptible flicker at this and at considerably higher rates, depending on the extent and nature of the difference. The minimum for the particular difference present is found by trial and error, and observations are then made with the photometer set at this rate or something very slightly in excess of it.

It has been found that with this form of photometer the results obtained by different observers are relatively precise and consistent, provided certain conditions are fulfilled as regards the size and brightness of the field of view and the provision of a steady background of about the same brightness. Even under the best conditions, however, different observers do not obtain quite the same results when the colour difference is large, and it is then necessary to select observers whose colour response is close to that of the agreed 'standard' observer. For this purpose, each potential observer makes a measurement of two sources with a certain definite colour difference. These are obtained by the use of two liquids, one yellow

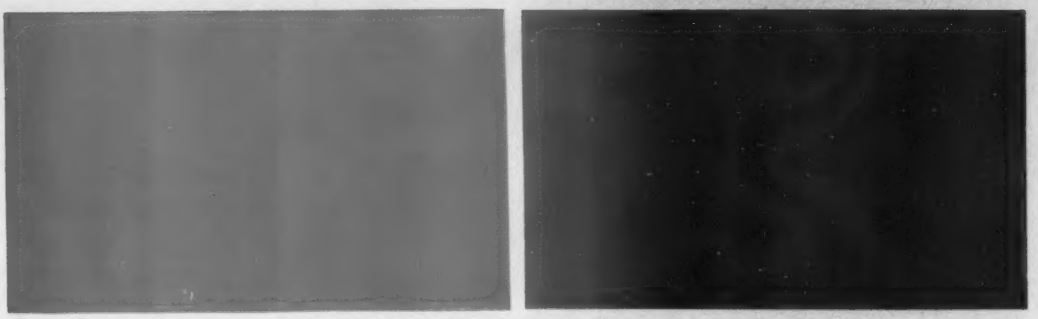


FIGURE 1 – *A measurement of the relative brightnesses of two coloured surfaces such as those shown above is subject to large uncertainties even for observers with normal colour vision.*

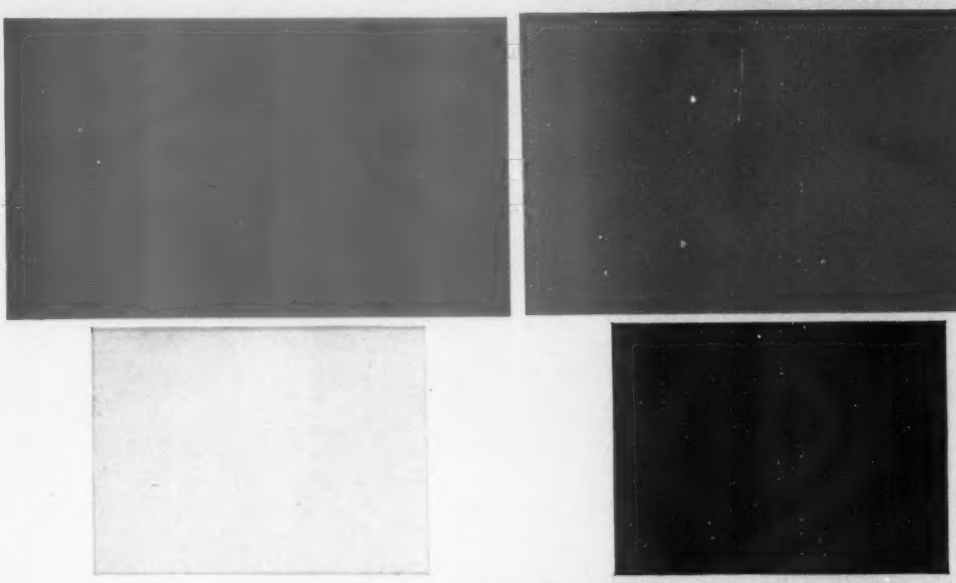


FIGURE 2 – *The grey patches show the relative brightnesses at very low illuminations of two lights, one green and one red, which appear equal at ordinary illumination values.*

FIGURE 3 – *The coloured slides used in ships' navigation lights and the limit glasses used in testing them.*

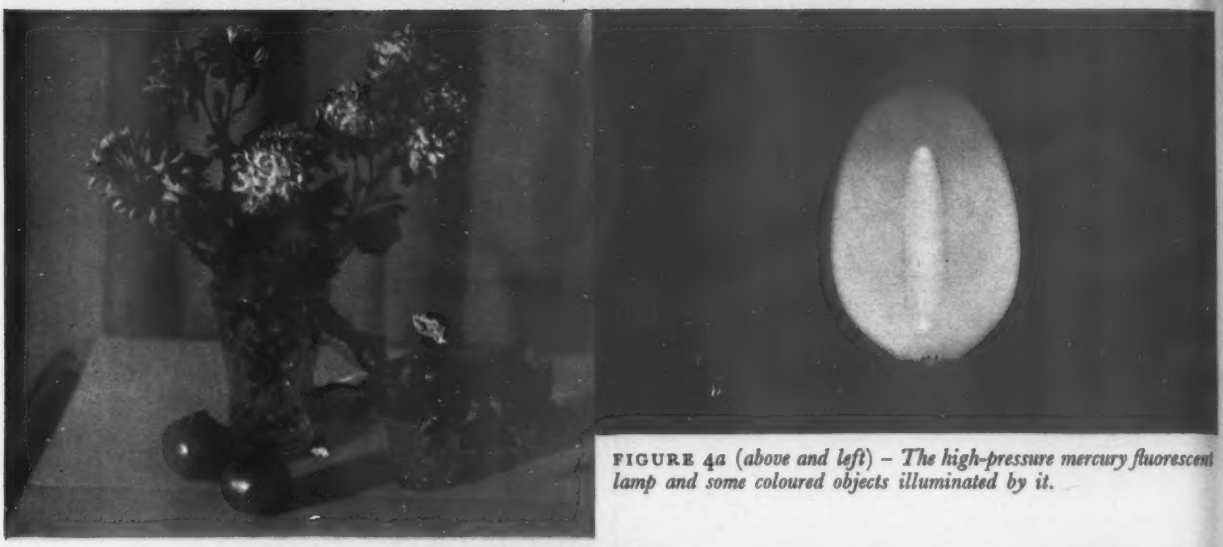


FIGURE 4a (*above and left*) – *The high-pressure mercury fluorescent lamp and some coloured objects illuminated by it.*

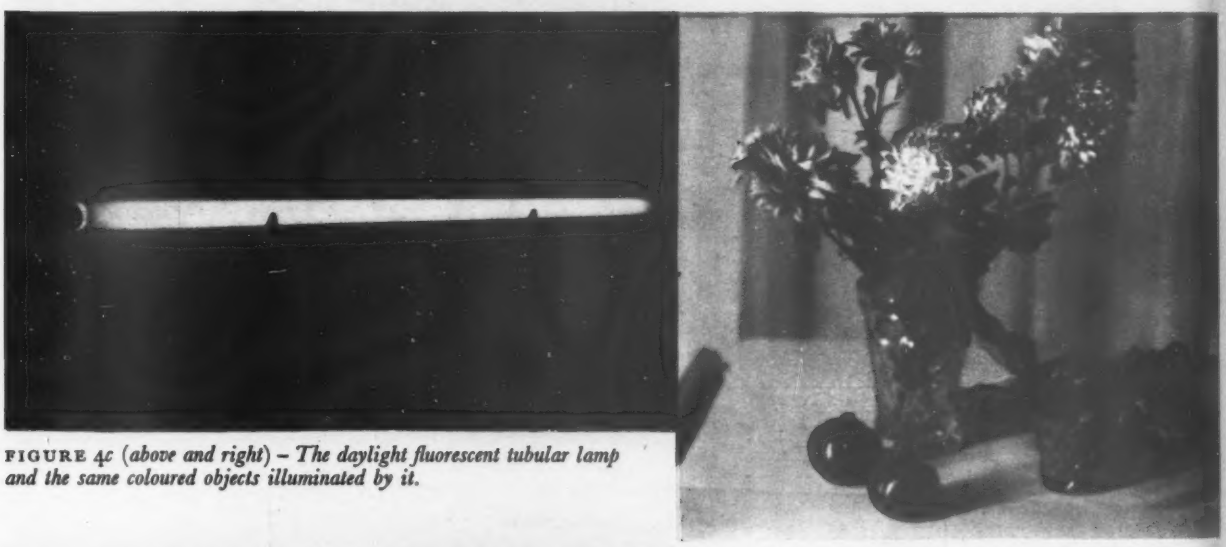


FIGURE 4c (*above and right*) – *The daylight fluorescent tubular lamp and the same coloured objects illuminated by it.*

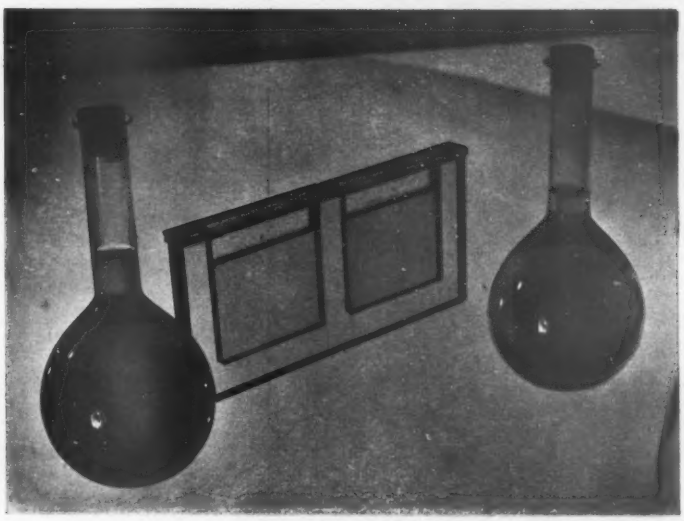


FIGURE 5 – *The blue and yellow solutions used for testing an observer's suitability for making measurements of coloured lights.*

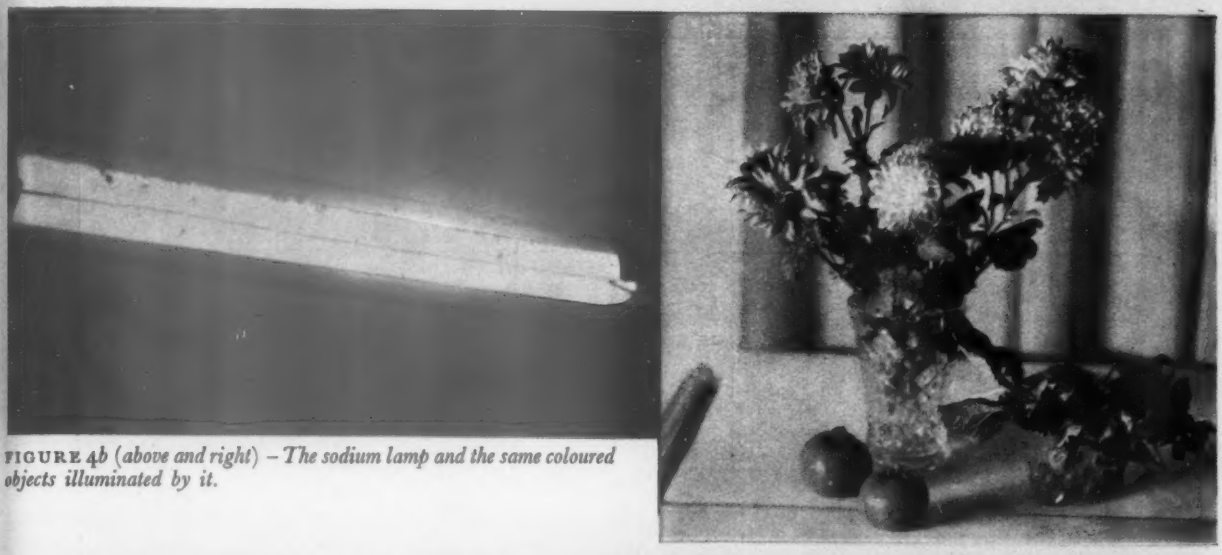


FIGURE 4*b* (*above and right*) – *The sodium lamp and the same coloured objects illuminated by it.*

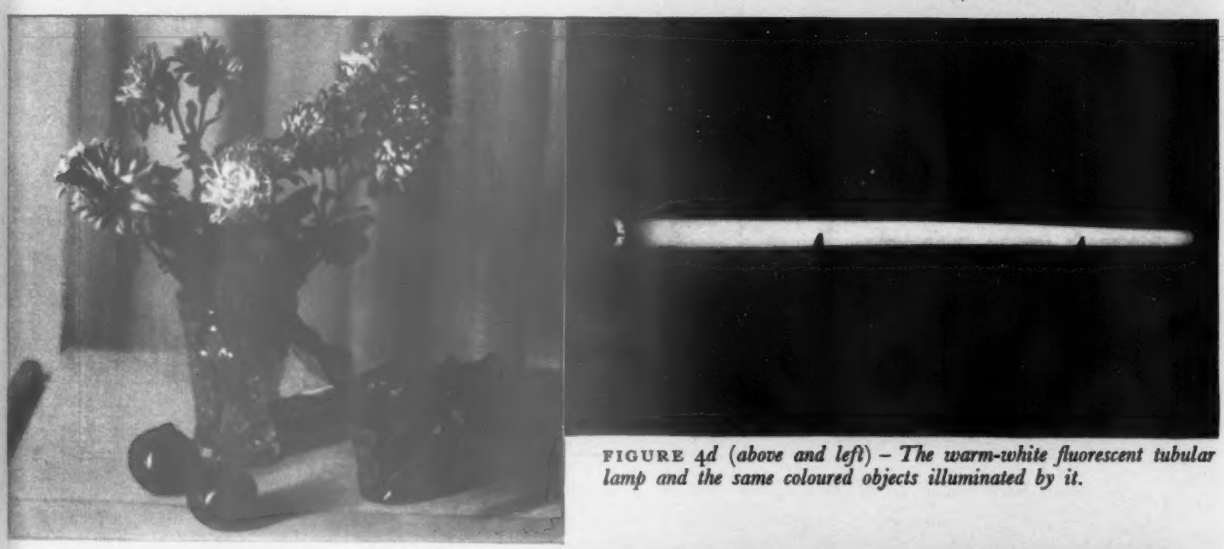


FIGURE 4*d* (*above and left*) – *The warm-white fluorescent tubular lamp and the same coloured objects illuminated by it.*

FIGURE 6 – *The liquid colour filter (and the component solutions) used in combination with a rectifier photocell to give a colour response similar to that of the average eye.*

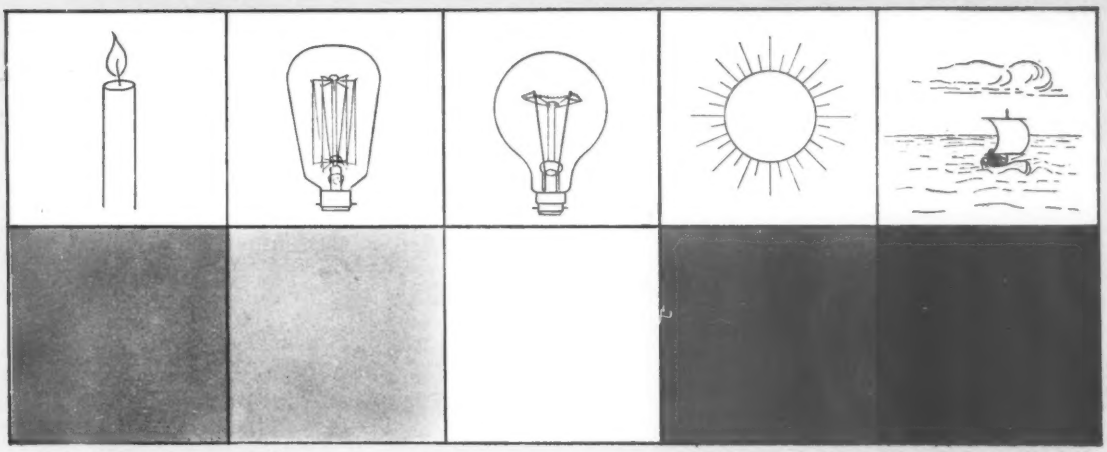


FIGURE 7 (*above*) – *The square patches show the colours of the light given by different familiar illuminants, viz. the candle, a tungsten-filament vacuum lamp, a gas-filled lamp, the sun, a blue sky.* (*The patches should be viewed by the light from a gas-filled lamp.*)

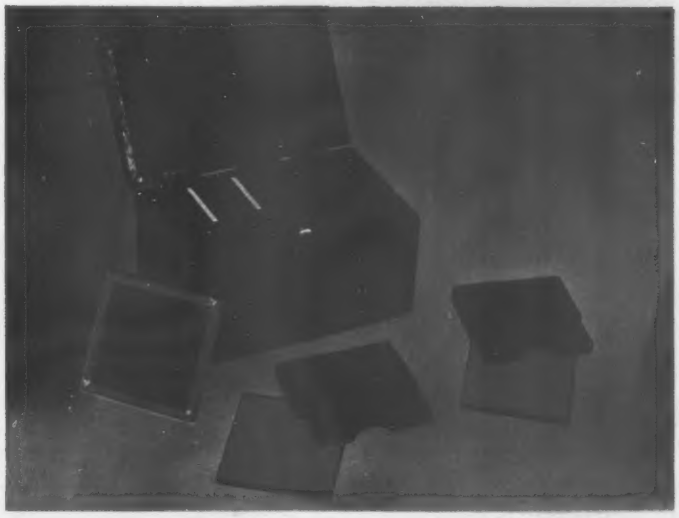


FIGURE 8 (*right*) – *Colour filters used in measuring sources of light of different colours.*

FIGURE 9 (*left*) – *Photo-electric cells used for light measurement. On the left a photo-emissive cell; on the right a photo-voltaic or rectifier cell.*

and one blue, of specified composition and thickness. The double glass cell containing the two solutions is shown in figure 5. The ideal observer, using a flicker photometer, will find that these solutions transmit the same fraction of the light given by a lamp under-run to match a carbon-filament lamp. An observer whose results depart from this condition by not more than about 5 per cent. may be regarded as having a satisfactory colour response for ordinary heterochromatic measurements.

COLOUR-CORRECTING FILTERS

Instead of using a flicker photometer it is sometimes more convenient to remove the colour difference, either completely or to a large extent, by means of a coloured glass or a liquid solution inserted in the path of one of the lights being compared. Naturally, the fraction of the light which gets through the coloured medium must be known. Generally it is calculated from a curve showing the percentage transmitted at every wavelength throughout the visible spectrum.

This method is used for the photometry of tungsten-filament lamps or other sources in which light is produced by raising the temperature of a solid body, such as carbon or a metal filament, to incandescence. It can also be used for measuring daylight or sunlight. Figure 7, viewed by the light from an ordinary tungsten gas-filled lamp, shows approximately the colour of the light emitted by such sources.

The correcting filters are, of course, similar in colour, and specimens of the actual filters employed are shown in figure 8.

GAS-DISCHARGE AND FLUORESCENT LAMPS

The recent introduction of gas-discharge lamps, in which the light is produced by an electric discharge passing through mercury or sodium vapour, has brought into great prominence the difficulty of measuring light having a very marked colour. Typical lamps of this type are shown in figures 4*a*, *b*. A still more recent development is the fluorescent lamp, in which the colour of the light from the mercury discharge is changed by means of a coating of fluorescent powder on the walls of the glass tube in which the discharge takes place. Two such lamps are in common use. In one the colour of the light approximates to daylight; in the other it is a 'warm' white.

The colours of the light given by these four types of lamp are shown in figure 4. Each of the four pairs of pictures shows, side by side, (*i*) one of the lamps mentioned and (*ii*) the appearance of a group of flowers, etc., when seen by the light from a lamp of this type. The light from such lamps is measured either by means of the flicker photometer or by using colour filters specially designed to give a match with the coloured light when placed in front of a tungsten-filament lamp.

PHYSICAL PHOTOMETRY

For many types of photometric measurement it is possible to use a photo-electric cell in place of the eye. Such cells are of two types, and a specimen of each is shown in figure 9. The cell on the left is of the 'photo-emissive' type, in which the light to be measured falls on a sensitive metal surface contained within a glass bulb which is either evacuated or contains an inert gas at low pressure. The bulb contains also a wire mesh, and this is connected to the positive pole of a battery, the sensitive surface being connected to the negative pole. The voltage between the sensitive surface and the wire mesh is of the order of 50 volts. When light falls on the cell a small current flows in the circuit, owing to the emission of electrons from the sensitive surface brought about by the light falling on it. Under carefully controlled conditions this current is proportional to the light falling on the sensitive surface, so that the device can be used for light measurement.

The other type of photo-electric cell, shown on the right in figure 9, is quite different in principle and is known as a 'photo-voltaic,' or sometimes as a 'rectifier,' cell. It consists of an iron plate covered with a layer of a semi-conducting material (usually selenium), which in turn is covered with an exceedingly thin layer of a metal such as gold or platinum. When light falls on this layer, a portion of it penetrates to the selenium, and if the layer and the iron plate are connected through a sensitive electrical measuring instrument a very small current will be seen to flow in the circuit. Again, under proper conditions, this current is proportional to the light falling on the cell. Advantages of this type of cell are its portability and the fact that it needs no auxiliary battery, the current being generated by actual conversion of the light energy.

As might be expected, no cell shows a colour response which is the same as that of the standard 'average' eye, and while this is immaterial so long as there is no difference in the colour of the lights being compared, it naturally introduces large errors when coloured light sources are being

measured. The difficulty is again overcome by the use of colour filters. In this case, to put the requirements in general terms, the filter must transmit well for a colour to which the cell is less sensitive than the eye and badly for a colour to which the cell is oversensitive. Although one cell differs from another in colour response, nevertheless the variation among cells of the same type is fairly small, and it is therefore possible to show a typical correction filter in figure 6. The liquid in the final filter is of a greenish colour, and is made up of three simple components shown separately in the three flasks.

MEASUREMENTS WHEN THE LIGHT IS DIM

The colour response of the eye remains constant so long as the brightness of the surface viewed is not reduced below that usual in a well-lighted room. For a much lower brightness, however, such as that of a surface seen by moonlight, the colour response alters very markedly. At such levels the eye's sensitivity to blue and green light, compared with its sensitivity to red light, is very much greater than at normal brightness levels.

The magnitude of this effect is illustrated in figure 2. To anyone with normal colour vision, the red and the blue patches appear approximately equal in brightness when seen by day. At a very low level of illumination, however, their relative brightness will appear more or less as shown by the two grey patches printed beneath them. Another illustration is provided by the appearance of a pathway illuminated solely by traffic lights at night. These lights are about equal in intensity, yet the pathway appears much brighter under the green light than it does under the red.

It will be clear, therefore, that the measurement of coloured light must always be carried out at a sufficiently high brightness.

SPECIAL PROBLEMS

As an example of a different type of measurement in which large colour differences are encountered, the control of the coloured glass slides used for ships' navigation lights may be mentioned. Two such slides are shown in figure 3. It is necessary that these glasses should be neither too dense nor too light and the control applied is to compare them with pairs of 'limit' glasses, one of each pair having the highest and the other the lowest permissible transmission. The limit-glasses used for the purpose are also shown in the figure.

Another example is the measurement of the brightness of the luminous markings on aircraft instrument dials. Some of these are of a radioactive luminescent material, like that used for the ordinary luminous watch, and the colour is a bluish green. Others are non-luminous in the dark but when illuminated by ultra-violet light glow with an orange-red colour. The brightness is measured by comparing the dial under test with a stencil of the same pattern which is placed in front of a sheet of opal glass or other translucent material. This is illuminated from behind by a lamp, the candle-power of which can be varied at will by the observer. A filter is used in front of the lamp to give a colour match with the dial, and the candle-power of the lamp is adjusted until the dial and the stencil appear to have the same brightness. The stencil can then be removed and the brightness of the translucent window measured by means of a suitable type of photometer. The effect of the filter can be allowed for in one of two ways. Either the brightness of the translucent window can be measured with the filter removed, the results being then multiplied by the transmission factor of the filter, or a second similar filter can be inserted in the photometer so that there is no colour difference when the brightness measurement is made. In this case the transmission factor of the filter is allowed for in the calibration of the photometer. This particular problem in heterochromatic photometry is often complicated by the fact that the brightnesses used are in the region where the visual phenomenon mentioned in the last section has to be taken into account.

CONCLUSION

It will be clear from all that has been said above that the measurement of coloured light is beset with many possible sources of error, so that the results can never be as accurate as those in which no colour difference is involved. Nevertheless by the adoption of the methods described, an accuracy sufficient for most commercial purposes can be obtained.

It is interesting to note that the difficulty was recognized by the earliest workers in this field of measurement, for Bouguer, who has been called the 'father of photometry,' describes as 'embarrassante' the comparison of two lights of different colours, and Lambert, writing in 1760, says 'Aegre comparantur claritates, quae colore plus minusve differunt.'

The author wishes to express his thanks to his colleague, Mr J. S. Preston, and to Mr E. B. Sawyer, Director of the E.L.M.A. Lighting Service Bureau, for their help with the illustrations.

The museum as an aid to popular science

F. S. WALLIS

The educational and cultural value of museums is frequently underestimated through failure to recognize how greatly museums of today differ from those of even a few years ago. Dr Wallis here describes the kinds of scientific work museums are now undertaking, and makes a number of constructive suggestions for their future development. Himself the director of a large city museum, he realizes the handicaps that museums still suffer, but his vision of the possibilities is invigorating and should be of particular interest to scientists.

The term 'museum' has for many years conjured up visions of dust, dirt, and endless rows of specimens, arranged with a soulless, meticulous care. It is thus difficult for many to realize how great a revolution has taken place, making the museums of their maturer years far different from those associated with their childhood. The name remains unaltered, but the ideas and aims of present-day curators are far removed from those of their predecessors of even fifteen or twenty years ago.

Museums originated as the systematic and public expression of man's inherent tendency to collect and conserve. As might be surmised, objects of natural history and ethnological interest were the first to attract him, and vast and unwieldy collections of these materials were the result. Those in charge were concerned firstly with the acquisition and preservation of the material entrusted to their charge, and secondly with its systematic arrangement. This latter function was carried out in a strictly scientific manner according to the latest classification available. Serried rows of objects resulted, and with little attempt to make the display attractive it is small wonder that museums lacked inspiration and vitality. They made little appeal to that final arbiter, the general public, and consequently lacked funds and adequate man-power. Notwithstanding such adverse factors, museums achieved much, for their first great task was to collect, describe, and exhibit the contents of the world. The Linnean system provided the basis for this mighty inventory as far as natural history was concerned, and various other classifications were used in anthropology and archaeology. That the task was well done is evidenced by the mass of descriptive literature which resulted, much of which was compiled, directly or indirectly, by members of the curatorial profession.

It might perhaps be interpolated here that recent practice has tended to separate the work and activities of museums and art galleries. There is a growing consensus of opinion that, in the larger centres of population at least, such a course is desirable, though it is also stressed that the buildings in which the museum and art gallery are housed should be adjacent. This article deals exclusively with museums.

Museums provide for the *whole* public and are visited for many different reasons. Firstly, there are the 'umbrella' folk who enter to escape a passing shower, though even in that transient state they should be catered for by some arresting exhibit; secondly, intelligent and interested laymen, members of local cultural societies and students who wish to know more about their own particular branch of knowledge; and thirdly, those who are capable and desirous of conducting research in their own well-defined fields. In any discussion on the relationships of science and the museum these three types of individual should be kept in mind.

Those responsible for the policy of museums at the present time are increasingly conscious of the fact that to the functions of collection and conservation must be added that of pleasurable instruction. The material must be interpreted to the public, and the vast stores, accumulated in some instances throughout a period of over a hundred years, must be turned to the educational and recreational advantage of the community. The recent Education Act makes it quite clear that in Britain opportunity will be given to all to develop whatever talents they may possess, and to learn more about their fellow men and environment. This is a wonderful opportunity for museums to make science, in its broadest conception, known to the public. Alone amongst public services the museum makes use of the three-dimensional, visual method of education. The basis of the craft of a museum curator is that he enables people actually to see the object rather

than to read or hear descriptive phrases concerning it. An object in a museum, accompanied by well-chosen, related material and provided with carefully written labels, is a powerful though silent source of instruction. With these factors in mind, we can now discuss how museums may develop in the future as an aid to science and as a help towards bridging the gap between the scientist and the layman—a gap which increased specialization tends to widen.

In the first place, museums can use their present material to illustrate and interpret the more traditional sciences—botany, geology, zoology—according to modern ideas. They can, for instance, show that ecology may be much more interesting than taxonomy. This indeed is a natural development of the previous period in the history of museums devoted to collection and description. The entrance hall or vestibule of the museum could be used for a large diorama portraying a typical glimpse of local scenery complete with the associated plants and animals. In such a display it might be possible to use carefully selected masses of the local rock, together with plants, shown either as life-like models, or by carefully preserved natural specimens, and typical animals set in characteristic attitudes. A scene (figure 1) typical of the Gower Coast and shown at the National Museum of Wales is an excellent example of this method of presentation. In some regions one such exhibit might be sufficient; in other more fortunate areas where several completely different types of scenery occur, more than one diorama would be needed. The scenic and ecological displays could be supplemented by realistic groups portraying local civilization in the prehistoric and historic periods, as far as these come within the policy of the museum. Such 'entrance hall' exhibits, adequately lighted by modern fluorescent tubes, would prove arresting to the 'umbrella' type of visitor. If the storm were of sufficient duration he might carry away a permanent impression of principles underlying the formation of the scenic beauty and the associated plant and animal life of at least one portion of his environment.

Although such exhibits would be of interest to the more serious layman, his requirements are more detailed, and for him a series of galleries portraying the principles of the sciences of geology, zoology, botany, and archaeology is necessary. By means of a simplified planetarium, or perhaps an orrery, the visitor is led to contemplate the earth as part of the solar system. The immense distances involved and the relative sizes of the sun, earth, and other planets can be shown graphically, and the visitor is then naturally drawn on to a study of the earth itself. Here the broad principles of rock formation, folding (figure 5), and destruction, can be shown, and the forms of early life illustrated by well-chosen, preferably local, examples.

The visitor might now be led—one-way traffic should always be planned in museums, even if the more impatient continually short-circuit the route—to the always popular zoological department. Here again the aim should be not so much to provide a correctly named example of each animal in the region, or—if means parallel ambition—perhaps in the world, but to display such material as shall draw attention to basic principles and relationships and to typical examples of the various phyla. As with the other traditional museum subjects, the application of zoology to everyday life is the important aspect to be stressed. This is particularly well illustrated in an exhibit at the National Museum of Wales, which deals with the animal life of a town and the alterations which might be effected in it by modern planning.

Again, in botany, the temptation to provide a faultless but monotonous record of the flora of the area must be avoided, and natural associations, together with ideas concerning plants as living organisms in a definite environment, should be emphasized. A stand exhibiting wild or cultivated plants of the region with another for experiments with living plants is an essential and ever-popular display. Agriculture, horticulture, and forestry offer a wealth of ideas for exhibits of this type. It cannot be too strongly stressed that the museum of the future will be concerned more with ideas than with objects. Galleries illustrating themes such as evolution, heredity, man's conquest of material, or transport through the ages (figure 4), will replace systematic and uninspiring series of stuffed animals, dried plants, and minerals.

With such a background of ideas connected with environment, the visitor naturally passes to a study of man and his works. This is a vast subject, and the available material is increasing daily. This section naturally commences with a study of man himself: the success of the Newark Museum in this direction is outstanding (figure 2). Most museums possess objects from the prehistoric and early historic periods of their own areas, often together with a superabundance of ethnological material illustrating the arts and crafts of various native peoples. Such material lends itself to

FIGURE 1 – *An exhibit in the Botanical Department of the National Museum of Wales, Cardiff, showing rock plants from the Gower Coast growing on limestone.*

(Courtesy of the National Museum of Wales.)

FIGURE 2 – *'Man' alcove. A striking exhibit arranged according to modern display methods and indicating the construction and working of the human body.*

(Courtesy of the Newark Museum, Newark, New Jersey.)

FIGURE 3 – *An exhibit to illustrate weather — generally regarded as a subject unsuitable for museum presentation. Newark Museum has prepared a successful exhibit by means of photographs and simple diagrams.*

(Courtesy of the Newark Museum, Newark, New Jersey.)

FIGURE 4 – *Transport in the early nineteenth century. A diorama in the Children's Gallery, Science Museum, South Kensington.*
(Courtesy of the Science Museum, South Kensington.)

FIGURE 5 – *Models in the Geological Department at the National Museum of Wales, Cardiff, illustrating stratification and folding of rocks. Experience has shown that such an exhibit is understandable even without labels.*
(Courtesy of the National Museum of Wales.)

FIGURE 6 – *'New contacts change cultures' displays by modern technique the lines of change in varied types of artifacts—war clubs, pipes, spoons, and so forth—laid against four time zones.*
(Photograph by Harvey Croze; courtesy of the Cranbrook Institute of Science, Michigan.)

modern display methods, and the ingenious techniques which have been such a feature of the various war-time exhibitions sponsored by the Ministry of Information and other organizations will surely find their place in the museums of the post-war period. Indeed a striking exhibit at the Cranbrook Institute of Science, Michigan (figure 6), consisting of relatively few specimens arranged concentrically, indicates that such display methods have already been adopted. The tendency to show extensive typological series must be avoided, and the everyday life of the ordinary man and woman in the various historical periods —and, in a large museum, in various parts of the world—must be portrayed with all the vividness which curators can command. Recently, the immediate past has claimed the attention of museum committees, and the science of folk-life has been introduced. This deals with the crafts and industries of about the last three hundred years, and seeks to show how our forefathers lived and worked. It is a fascinating branch of science, still in the fact-collecting stage, though tentative and limited hypotheses are emerging. This branch of knowledge has a special value in that it invites the visitor to carry out simple observations for himself on intensely humanistic subjects, and it has inspired many a layman to collect facts in and about his own neighbourhood. To many, the museum clearly demonstrates that the first stage in any science is the collection of facts and evidence and not the formulation of a theory or hypothesis.

In addition to the entrance hall and the general exhibition galleries, there should be a series of rooms available only to the more serious student. These would contain the greater portion of the collections, arranged with careful precision and labelled according to the latest nomenclature available. This section provides the material for research—another important function in the policy of a progressive museum. The traditional museum subjects can thus be displayed more in accord with the results of modern science. Museums provide science with an effective and visual interpretation of its latest trends of thought, as well as with a mass of well-authenticated material for future research.

The interest of the general public in science, however, is swinging over to the astronomical, physico-chemical, medical, biological, and engineering aspects. Atomic structure is of greater present interest than butterflies and fossils. Although a few museums have displayed material and ideas illustrating some aspects of these sciences, it now appears certain that our institutions must seriously consider and meet this new demand, thus seizing their opportunity as the chief exponents of visual education.

Astronomy has already been mentioned as providing an introduction to the study of geology. But it can be treated in a far more detailed manner, and the recently increased popular interest in this science should be stimulated. In addition to the models already mentioned, the museum could exhibit other working models, with simple explanatory data, illustrating such matters as lunar and solar eclipses. The historical development of ideas concerning the birth of the earth is capable of demonstration, as are the astronomical uses of the telescope and spectroscope.

In illustrating chemical science in the museum, heed must be given to the *applications* of systematic knowledge, especially in local technical processes. The layman today wants to possess an increased understanding rather than to assimilate additional facts and curiosities of information unrelated to his individual problems. Although many local products are shown in the art gallery as works of art, it is in the province of the museum to demonstrate the technical processes involved in their production. New materials such as plastics, rayon, and the many other synthetic materials which have appeared in the last few years, can be exhibited and explained, with outlines of the methods used in their manufacture. A few simple experiments which could be set up and worked by the pressure of a button would be of value. Such exhibits will soon dispel the all too prevalent idea that it is only when articles and ideas are entirely out of date that they should be included in a museum. Museums can thus act to the public as the popular expositors of both the academic and the industrial chemist.

The ordinary man or woman is intensely interested in modern theories regarding the constitution of matter, as witness the extraordinary appeal of all literature relating to the atomic bomb. Much of this, together with the principles of X-ray analysis, is capable of visual illustration.

In many subjects, museums can provide the stable historical background which gives the basis for the solution of present day problems. This is especially true in physiology, anatomy, medicine, and even in psychology and sociology. Museums must show how the nation lives and works for its means of existence; how it deals with nature and its products. Exhibits illustrating the health and

food of a nation, the many basic facts required for town and regional planning, and the technical processes involved in the preparation of new materials, are amongst those which indicate the new approach to subjects hitherto neglected. At the Newark Museum (figure 3), even a non-objective subject such as the weather has provided material for an exhibit.

Initiative is the essential factor for success in such museums of modern science. Diversity and not uniformity must be the keynote in museums as it is in the British nation. Museums today are in a state of transition from a well-established past, through a rather confused present, to a period of closer contact with the life of the community in the future. Science is daily achieving a greater mastery over matter in all its forms, and it is essential that museums should be to the fore in making this new knowledge available to the public, who must be, and indeed desire to be, kept informed of recent advances in science.

The new concept of museums as mouthpieces of modern science necessitates the close co-operation of scientific societies and specialists; it is only by their assistance and advice that museums can operate in these new fields of knowledge. Such relationships are of double benefit, for while museums inform the public of the progress of science and the work of scientists, they are also of service to scientific workers in their researches. Formal education is a process which is completed and not repeated, but true education, which is an awareness and appreciation of man and his environment, is never completed. It is the visual interpretation of this concept of education that lies within the province of museums to encourage and stimulate. By covering the whole field of science, museums can do much to enable individuals to discover and develop their particular interest in specific branches of the subjects.

Science, museums, and the interested layman form the three components of a system in which each is of service to, and mutually dependent on, the others. The interpretation of science is a formidable task and many expositors must be used. Not the least of these will be the objective value of a museum of science.

The author wishes to tender his grateful thanks to all those colleagues who in conversation or correspondence have discussed with him some of the matters in this paper.

Sir James Hopwood Jeans, O.M.

It is with deep regret that we record the death, on 16th September, of Sir James Hopwood Jeans, O.M., F.R.S., at the age of 69. Jeans was known throughout the world not only for his many original contributions to mathematical physics but also for his lucid expositions of science in books and articles intended for the general public. His academic career was a brilliant one, and among the positions he successively held were those of Professor of Applied Mathematics at Princeton (1905–9), Stokes Lecturer in Applied Mathematics at Cambridge (1910–12), and Professor of Astronomy in the Royal Institution. He held also many important offices and was at various times Secretary of the Royal Society (1919–29), President of the Royal Astronomical Society (1925–7), and President of the British Association for the Advancement of Science (1934). He was honoured by universities and societies throughout the world, and received, among other awards, the Royal Medal of the Royal Society, the Gold Medal of the Royal Astronomical Society, and the Franklin Medal of the Franklin Institute.

One of Jeans' first major contributions to science was his confirmation of Lord Rayleigh's law for black-body radiation. In this field he quickly recognized the significance of Planck's quantum theory and used it skilfully to develop his own theories. He gave too, in 1903, the first rigorous proof of Maxwell's law for the distribution of velocities among the molecules of a gas. Although his work materially advanced many branches of physics, Jeans is most generally known for his cosmogonic work. His brilliant theories of the origins of the planets and their satellites and of the source of stellar radiation have gained wide, if not universal, acceptance. He will be remembered too for his philosophical interpretation of modern science. Though his philosophical theories have excited much controversy, they represent a courageous and carefully considered attempt to answer problems whose manifest difficulties have deterred most of his contemporaries. His death is a severe loss to British science, the more so as it comes at a time when the rapid advancement of science is creating so many urgent philosophical problems. Jeans took a keen interest in ENDEAVOUR from its earliest days and was a valued contributor.

The fluorescence of organic compounds

N. CAMPBELL

The study of inorganic fluorescent substances has led not only to results of value in the understanding of atomic structure but to the commercial development of the fluorescent lamp, described in the January issue of ENDEAVOUR. In the organic field too, fluorescence has proved of both theoretical and practical importance. Although the fundamental problem of the relationship between fluorescence and chemical constitution remains unsolved, its study has resulted in a wide knowledge of the facts relating to the phenomena.

'Nature is full of exquisite sights and sounds' wrote an English essayist, and of these 'exquisite sights' pride of place must surely be given to colour, whether it be in plants or in flowers, birds, or butterflies. Nor are the synthetic products of the chemist lacking in this respect: many and varied indeed are the colours to be found on laboratory shelves or in dyers' catalogues. Certain dyes are found to possess a characteristic brilliance known as *fluorescence*, the most familiar example of which is the vivid green shimmering colour obtained by adding the dyestuff fluorescein to an aqueous alkaline solution. Briefly defined, fluorescence is the property possessed by many substances of absorbing light of a certain wavelength and emitting part of it again as light of a greater wavelength.

Fluorescence was observed and recorded hundreds of years ago: Boyle, for instance, noted the colour of the extracts of certain woods. Later investigators, including the famous Scottish physicist, Sir David Brewster, joint founder of the British Association, studied the phenomenon, but though much of their experimental work was excellent, small progress was made on the theoretical side. It was not until 1852 that Sir George Stokes attacked the problem with systematic thoroughness, and gave a lucid account of the true nature of fluorescence.

FLUORESCENCE

To most of us, light means colour, so-called 'white' light being a mixture of the colours of the spectrum. Expressed in another way, white light is composed of light of different wavelengths. In the short-wave region appear violet and blue, and at the other end of the spectrum is red. Visible light, however, is only a limited range of light: adjacent to the ends of the visible spectrum are other forms, known respectively as *ultra-violet* and *infra-red* light.

Though ultra-violet light, like other radiations such as wireless waves, is invisible to the human eye—it is sometimes known as 'black' or 'dark' light—its presence is easily detected in several ways. For instance, it darkens silver chloride and hence can be detected photographically. Its existence is shown more strikingly, however, by the colours, often of astonishing brilliance, which are produced when its invisible rays fall on certain minerals or chemicals. One of the best known of these is fluorspar (calcium fluoride), which fluoresces in ultra-violet light with a beautiful blue colour. Stokes, who observed this fact, invented the term fluorescence for this type of luminescence.

In the present article we shall confine ourselves for the most part to the fluorescence of organic compounds in ultra-violet light.

FLUORESCENCE OF ORGANIC COMPOUNDS

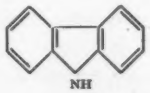
Ultra-violet light is most conveniently obtained from the mercury-vapour lamp, most of the visible rays being removed by means of a suitable glass filter. In this light it is probable that the majority of organic compounds fluoresce, but only in a small number of cases is the phenomenon easily observable. The following list (p. 156) gives some typical fluorescent organic compounds.

It is of interest that many compounds, such as quinine sulphate and anthracene, are colourless in ordinary light but may be detected and identified by their characteristic fluorescent colours in ultra-violet light. It must be remembered, however, that fluorescence may be, and often is, due to the presence of minute quantities of impurities. The classic example of this is found in the coal-tar hydrocarbon fluorene, which was first isolated by Marcellin Berthelot in 1867 during his famous researches on the pyrogenic hydrocarbons. Berthelot was so impressed by the fluorescence of this compound that he called it 'Fluorène.' Yet

Organic Compounds fluorescent in Ultra-violet Light	
Benzene	*Feeble violet*
Stilbene	*Blue-violet*
Naphthalene (pure) ..	*Slight violet*
2 : 3-Dimethyl naphthalene	*Blue-violet*
2 : 7-Dimethyl naphthalene	*Feeble violet*
Anthracene (pure) ..	*Bright blue*
Anthracene (technical)	*Bright green-yellow*
Phenanthrene	*Violet*
Fluoranthene	*Brilliant green*
1 : 2-Benzanthracene ..	*Blue*
2 : 3-Benzanthracene ..	*Orange*
Pyrene	*Brilliant green-yellow*
Chrysene	*Bright violet*
Perylene	*Bright orange-red*
Carbazole (technical) ..	*Brilliant violet*
Carbazole (pure) ..	*Feeble violet*

fluorene when pure shows little or no fluorescence. A highly fluorescent commercial sample, for instance, when purified by chromatographic ad-

Fluorene



Carbazole

sorption, gives a beautiful white but non-fluorescent substance.

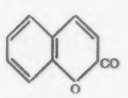
Carbazole, with a somewhat similar structure, is another compound generally regarded as fluorescent. Indeed, highly purified specimens have been authoritatively stated to possess bright fluorescence. We have found in our researches that synthesized carbazole has little or no fluorescence, and that chromatographic adsorption readily removes the fluorescent impurities from coal-tar carbazole.

Impurities influence the colour of fluorescence, and sometimes extinguish it completely. An illustration of the former effect is furnished by anthracene: this hydrocarbon when impure has a bright yellow fluorescence, but when pure it fluoresces blue.

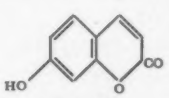
One of the most striking contributions of organic chemistry to medical science in recent years was Cook's isolation and identification of the carcinogenic compound in coal tar. The compound proved to be the aromatic hydrocarbon 3 : 4-benzpyrene, the isolation of which was made possible by its characteristic fluorescence. In vitamin research, another field intensively investigated, fluorescence has proved its worth. For example, vitamin A is readily detected by this means. A slice of tissue fixed in formaldehyde is illuminated with filtered ultra-violet light. If vitamin A_1 is present the specimen glows with a green fluorescence for a few seconds, while tissues with vitamin A_2 show a reddish glow. It is of interest that solid riboflavin gives a bright deep orange fluorescence, while in aqueous solution it gives a strong green one.

FLUORESCENCE AND CHEMICAL CONSTITUTION

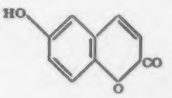
The organic chemist is never so happy as when engaged on that most elusive of problems—the correlation of physical properties and chemical constitution. Hundreds of papers have appeared in which colour and chemical constitution are discussed, and many workers have tried to correlate fluorescence and chemical structure, without, it must be admitted, much success. One or two useful empirical rules obtain. Bright fluorescence is observed mainly with polycyclic aromatic and heterocyclic compounds. This is evident from the above table and the coloured photographs. Fluorescence is also very dependent on the nature and position of substituents. For example, in alkaline solution coumarin does not fluoresce, while the 7-hydroxy derivative (umbelliferone) gives a beautiful blue fluorescence. The isomeric 6-hydroxycoumarin, on the other hand, does not



Coumarin



Umbelliferone



6-Hydroxycoumarin

fluoresce unless dissolved in sulphuric acid. No satisfactory explanation has been given for results such as these, and a general theory is still lacking in spite of the great number of available experimental data.

FLUORESCEIN

Probably the best-known fluorescent compound is fluorescein, which can readily be detected by the naked eye in an alkaline solution even at a concentration no greater than 1 in 40,000,000. With the aid of instruments it can be 'spotted' at great dilutions—somewhere about 1 in 200,000,000. This powerful effect has been utilized in many ways. One application, of particular value during the late war, is in saving life at sea. Rafts, which are not easily seen from the air, have a tin attached containing a fluorescein derivative. When the raft

FIGURE 1 (*right*)
Solid fluorescent compounds.
1. Anthracene (pure)
2. Anthracene (crude)
3. Benzpyrene
4. Phenanthrene
5. Pyrene
6. Fluoranthene

FIGURE 2 (*below*)
Fluorescent solutions.
(*Left to right*)
Coumaric acid (alkaline solution)
Quinine sulphate (water)
Perylene (ether)
Perylene (benzene)
Fluoranthene (benzene)
2 : 3-Benzanthracene (benzene)
Pyrene (benzene)
Phenanthrene (benzene)
Rhodamine B (glycerol-water)

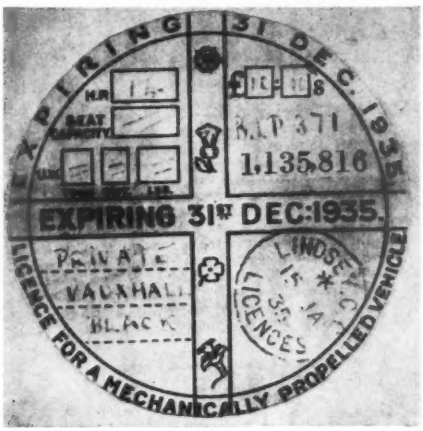


FIGURE 3*a* – *Photograph showing writing apparent to naked eye.*

FIGURE 3*b* – *Photograph taken under ultra-violet rays from mercury vapour lamp, showing writing which had been erased by chemicals.*

FIGURE 4*a* – *Sock photographed in ordinary light.*

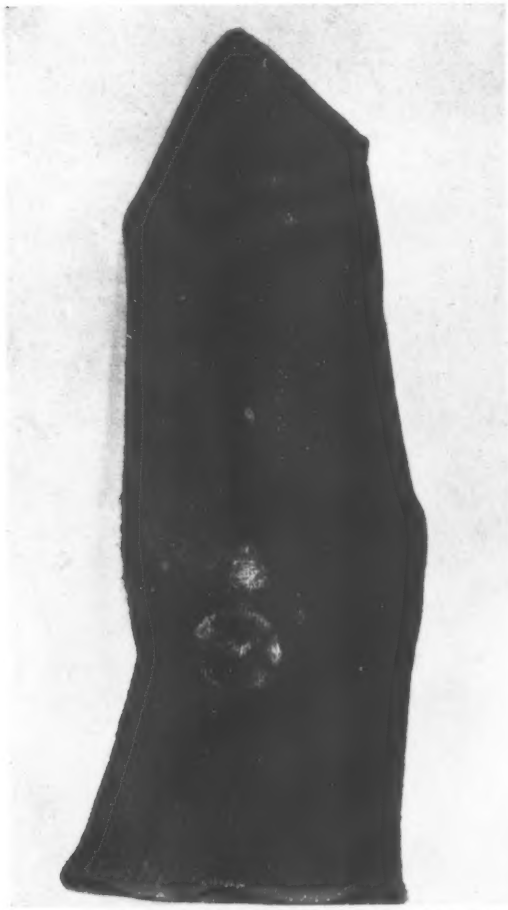
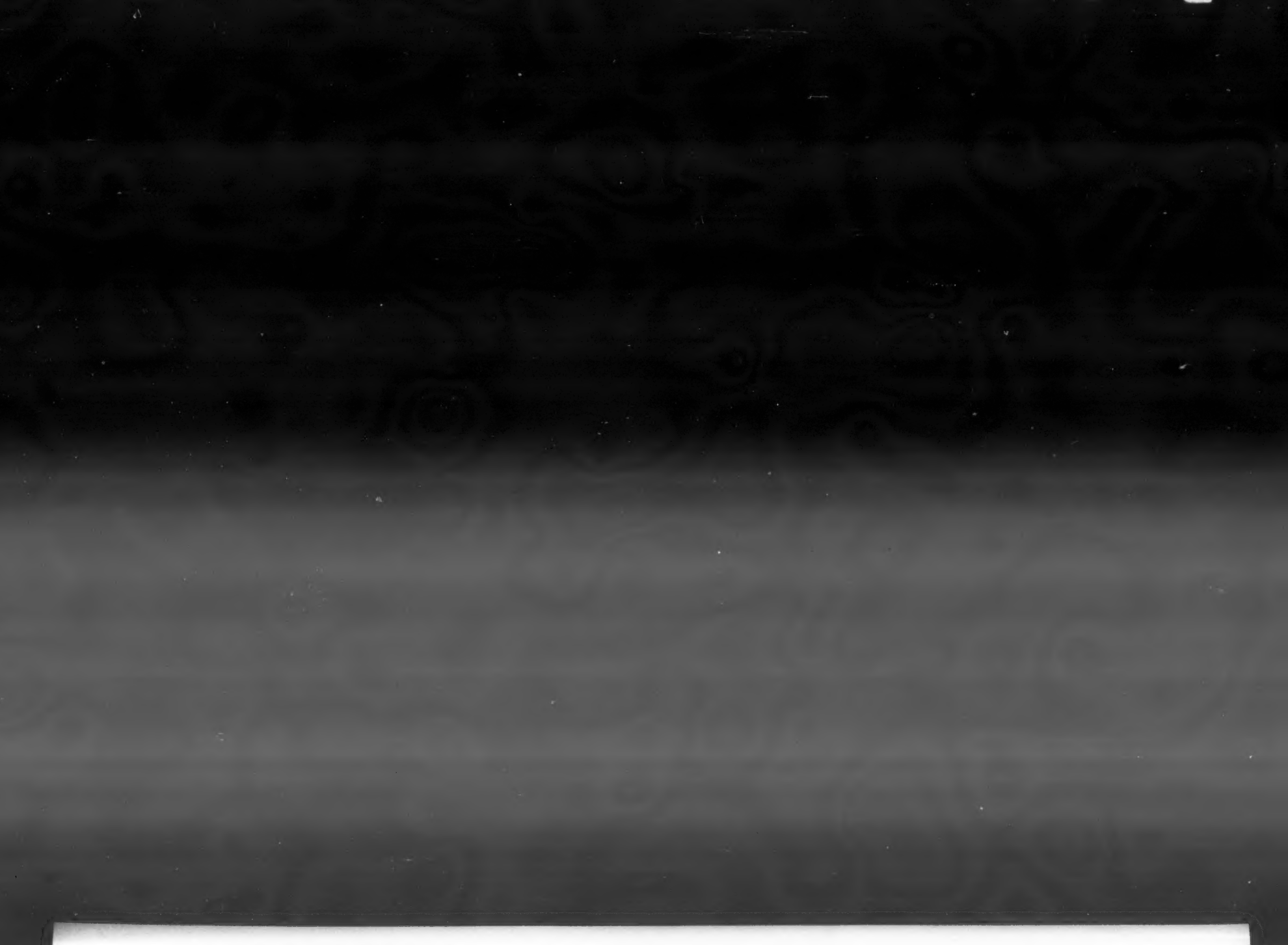


FIGURE 4*b* – *Sock photographed in ultra-violet light. The outlines left by coins are clearly seen.*



comes in contact with the sea it is soon surrounded by a fluorescent surface of considerable size, thus assisting patrolling aircraft in their rescue work.

Fluorescein has been much used in water-supply investigations and hydro-geology. For instance, the drinking-water of a South African city some years ago was found to contain *B. coli*. By means of fluorescein a rock fissure was discovered through which poisonous swamp water was flowing into the city's water supply.

In a similar fashion, underground water connections have been traced and canal leakages detected. But by far the most dramatic and interesting application of fluorescein was made some years ago by Norbert Casteret, who described his results in a thrilling and fascinating book *Ten Years under the Earth*. Since 1787 there had been great controversy over the origin in the Pyrenees of the Garonne, the river upon which the inhabitants of the Upper Garonne (France) are dependent. It was held by many 'arm-chair' geographers that the Garonne rises at a large spring called the Goueil de Jouéou, situated in the mountains at an altitude of 4,580 ft. Casteret, however, as a result of three years' intensive exploration, came to the conclusion that the Goueil de Jouéou was fed from the Trou du Toro, a torrent high in the Pyrenees and some miles distant. This bold theory had been mooted before but never substantiated. Casteret settled the problem once and for all in 1931 by pouring 120 lb. of fluorescein into the Trou du Toro at 8 o'clock on a July evening. In a few seconds the torrent assumed the expected green fluorescence. The production of beautifully coloured cascades, however, was not Casteret's aim, and with his companions he hurried to the Goueil de Jouéou. At 6 o'clock next morning they observed with excited delight that it too exhibited the vivid green fluorescence —a delight not shared by the local inhabitants, who viewed the 'diabolical' colour with superstitious alarm.

Casteret's discovery was not only of academic interest but of great economic importance, as there was a proposal afoot to divert the waters of the Trou du Toro for power in Spain. Casteret's work resulted in the project being dropped: otherwise the waters of the Garonne would have been halved, with serious consequences to the Frenchmen whose livelihood depended on that river.

CRIMINOLOGICAL INVESTIGATIONS

Many objects which in ordinary light excite little or no notice fluoresce distinctively in ultra-violet light, and it is therefore not surprising that fluorescence has proved of great service in criminal investigations. 'Invisible' inks show up splendidly, and erasures by chemical means are instantly detected in this light. Again, many postage stamps are of particular value without their postmarks, and 'used' stamps are sometimes treated most skilfully by experts, so that careful examination reveals nothing irregular: yet such erasures are obvious under the lamp. Genuine pearls, too, can be distinguished from artificial ones, but not, of course, from the cultured variety. It may be noted in passing that fluorescence is no respecter of persons: in the revealing rays of the ultra-violet light, hair dyes fluoresce strongly, while it has led many a blonde to admit her debt to chemistry in general and hydrogen peroxide in particular.

Space forbids more than mere mention of one of the methods used by the police. Fluorescent powders have proved of great assistance, and the following two investigations by the City of Edinburgh police are given to illustrate this.

Money disappeared on several occasions from a locked cabinet, and suspicion fell on a certain man. A sum of money was placed in the cabinet, some of the coins being powdered with anthracene and the remainder with another fluorescent powder. The box was later opened and 17s. were found to be missing, whereupon the detective officers called at the house of the suspect, who raised no objection to being searched. No money was found in his possession, but in ultra-violet light tell-tale fluorescence was observed on his trousers outside his pocket. Confession, however, was obtained only when the right shoe and sock were examined under the ultra-violet lamp: distinct fluorescent patches were to be seen on the inside of the shoe, while on the sock the well-defined outline of several coins could be seen (figure 4*b*). The coins when recovered still fluoresced strongly.

Figure 3 shows clearly that a road licence found on a motor-car in Edinburgh and appearing to refer to a 14 h.p. private Vauxhall black motor car had been issued for a 9 h.p. private B.S.A. green motor-car. It was by this means that inquiries were started which led to the arrest of thieves who had stolen the licence in London and were using a car hired in that city. When arrested they had in their possession two bottles of liquid capable of rendering the handwriting on a car licence quite invisible in ordinary light.

NOTE: I have to thank Chief Constable Morren, of the City of Edinburgh Police Force, for his courtesy in supplying me with information and photographs.

The values of science

E. F. CALDIN

Mr Caldin's article on the role of science in society, published in the April issue of ENDEAVOUR, aroused much interest. In this second article he discusses the relationship between science and the philosophical values of truth, goodness, and beauty. Such studies are of particular significance at the present time, when concentration upon the material aspects of science has created philosophical problems of international importance.

People associate two sets of values with science. One set is concerned with the advantages in material welfare that can be expected from technology based on science. The other is concerned with the values of science as such. It is with this second topic that I am to deal: the value to scientifically minded people of natural science and scientific life, considered in themselves and not as a means to improving material conditions.

I shall assume that we can assess the value of scientific knowledge by considering to what extent the picture of nature which it presents to us is characterized by truth, goodness, and beauty, and to what extent, further, this picture reveals to us the corresponding 'values' in material nature.[1] Truth is obviously connected with knowing, and goodness with loving; for brevity's sake we shall not delay longer on their definition. Beauty is closely connected with the other two values, and we may say that things are beautiful in so far as their truth and goodness lie open to our minds, so that we can grasp their forms intuitively. A friend is beautiful to us—more beautiful than a stone, say—because we have a certain intuitive knowledge of the character of the friend, and rejoice in it. We know a friend as a unity, a person, not as a series of episodes or actions; and by intuition, not by discursive reasoning. It is this intuitive knowledge of a lovable being which constitutes the perception of beauty. Thus beauty is one kind of good, arising from one kind of knowledge; and so it is intimately connected with goodness and truth. Further, it may be argued that truth, goodness, and beauty all depend on *form*—order, pattern, design, unity. A thing is both more knowable and more lovable the more developed is its form—a friend more than a squirrel, and a squirrel than a pebble. Now, it is in respect of form that these levels of existence—human, organic, inorganic—differ from one another. The material is the same for all—the same set of chemical elements, the same physicochemical laws—but the form of the man is a rational soul and so higher than that of the organism, which in turn is capable of growth, development, and reproduction, and so is higher than that of inorganic nature. And the higher form is at once more knowable and more lovable; and since it is more open to our intellectual grasp or intuition, and since when intuited it gives us the more delight, it is also the more beautiful. It is by degrees of form, then, that we can assess value.[2]

We can apply this treatment to beauty in art, and first to the 'fine arts.' These arts, I shall assume, are concerned with *significant* form: the artist must select and distil the data of experience so that the form he creates shall give an intuitive vision of some reality. What delights us at first sight in the work of art is the intuitive knowledge of its form. The prima facie beauty of a work of art is not the beauty of anything it represents; it has an independent beauty, related to the joy of seeing something as a whole, of reaching intuitive knowledge. If the reality of which the form is significant is beloved too, we are the more delighted, because of the further beauty that we reach through the work of art. We find a portrait as such beautiful because we see there condensed into one form the whole complex of a character, a human life; if the character is beloved too, we are the more delighted with this beauty revealed and intuited through art. A work of art, then—a significant form—opens to us both its own beauty and that of the reality it represents.

Evidently the greater the range and depth of the experience drawn upon, the greater will be

[1] For lack of space I have had to simplify very drastically the philosophical background here. I can only hope that the result is not misleading.

[2] Cf. J. Maritain, *Art and Scholasticism*, etc.; and various writers epitomised in E. F. Carritt's collection of texts, *Philosophies of Beauty*.

the work of art. We all think the *Divine Comedy* a greater poem than some slight lyric which may nevertheless be as adequate to its tiny theme as Dante's poem is to its mighty one. The work of art is the greater, moreover, the more the outer form is adequate to the reality represented. In proportion to the reality represented, the form must have a unified complexity, an ordered richness, a variety in unity. Variety in unity, indeed, will be a clue that we can use in treating of beauty in philosophy, in literature, in science, in mathematics. It is not the whole of beauty, but in discussing the value of an intellectual structure it is the characteristic by which one may best assess beauty. A table of integrals, for instance, is less intelligible and less beautiful than an elegant mathematical theorem, because our minds can seize the theorem as a whole but not the collection of integrals, which has no logical unity. We assess value in terms of form, and form in terms of unified variety.

We can now turn to natural science, and to material nature which is the source of its data. The values of the two are distinct. We may think of science as analogous to a work of art, in that it has its own form, constructed to reveal or be significant of the form of nature (or rather its quantitative aspect). We can treat science as, in the first place, a systematization of sense-data, a unification of measured quantities.[1] Measurements are brought into rational relations with each other by constructing functional relations from them, and these empirical laws are related by more general laws. These laws again are unified by the theoretical interpretation, from which (if it were complete) the empirical laws could be deduced, and thence the behaviour of experimental systems. It is in this unity, this form, that we can find the beauty of science; this is the kind of harmony, of variety in unity, that characterizes it. It is a unity in which are combined measurements of diverse phenomena, empirical laws, and theoretical interpretations of all degrees of generality; all are unified in so far as they are deducible as particular cases from the general theoretical interpretation. The unity is not solely a matter of the logical rigour of the theoretical interpretation (analogous to the logical rigour of mathematics); it is a richer unity, because experimental observations on material systems are unified within the logical scheme, in so far as deductions from that scheme are in agreement with them. This is the version of variety-in-unity peculiar to natural science. It occupies rather a low place among the many types of intellectual beauty—compared with the beauty of great poetry, of music, of philosophy, it is low indeed—yet it is genuine beauty, and it has its own appeal.

We can, however, consider science as not merely a unified scheme, but as a source of rational beliefs about material nature. Since it exhibits a logical order, and since it is based on experience of material nature, it evidently presents to us some image of the order in nature; of the form of nature, the causal interdependence of things and events. But the scientific scheme with its merely logical order cannot be an adequate account of the order of nature, which must be causal and not logical. It appears that in science we symbolize the causal order in nature by the logical order of the theoretical scheme, i.e. we symbolize causality by deducibility. This is the way in which science is significant of nature.

We can see why it is that physical science must be content with thus reflecting, rather than describing, the form of nature, if we consider the method of science. In physical observation we limit ourselves in two ways. In the first place we confine ourselves to material nature; we omit all consideration of human acts—such as those of the human agent, the experimenter—and of the First Cause, God, who holds nature in being. In the second place we confine ourselves to the measurable aspects of a material object. We find that there are relations between the measured quantities (such as length and temperature) which can be expressed in the form of equations, and we construct from these equations a theoretical interpretation which unifies them. Obviously this theoretical scheme will be mathematical, since it has to bring unity into a set of equations; it will itself be a set of equations from which the experimental relations can be deduced. Consequently the scheme will admit only inferences and must neglect causes. And it is evident that the reason why the scheme is mathematical is that at the start we confined ourselves to measurable characteristics. Thus the limitations of the theoretical scheme, as a source of beliefs about nature, are due to the very method of physical science.

Science, then, is not an adequate description of nature; it is a portrait, made by an observer with a particular point of view and a definite limitation on his vision. From natural science we cannot learn what material nature is for, how and why

[1] I deal throughout with physical science, but I believe that the situation would turn out to be fundamentally similar for the other sciences.

it exists at all, and why it has any laws. In so far as we can answer these questions we do it in terms of a wider survey, made explicit in philosophy and theology, expressed concretely in poetry, felt and lived vividly in the nature-ecstasies of a few. 'The man of science who wishes to make his expert knowledge contributary to an absolute wisdom must first complete it by making it a full knowledge of nature, not in all her details, but in all her aspects.'[1] We recognize such wisdom as good in itself—a worthy part of the pattern of a good life. It is, moreover, useful in living the good life; for to live rationally man must know his situation; he must have some knowledge of nature, man, and God. More generally, science gives us a new window on life; we get a better notion of truth, goodness, and beauty in general through it, because it gives us a wider range of examples to compare. Science can enlarge our outlook on life. But it will do so only if we examine its presuppositions and probe its deficiencies; otherwise it may shutter our windows one by one.

I have dealt so far with the values of science considered as knowledge. But scientific *life* has its values, which are only partly determined by the values of the finished scientific knowledge. We must consider the other ways in which the good life for scientists is influenced by their work.

The first way is that scientific life is a simplified version or microcosm of rational life. This view was elaborated in an earlier article[2]: briefly, it was suggested that scientific life requires (*a*) an inquisitive care to establish facts, and (*b*) an effort to interpret and synthesize them, and therefore (*c*) a unity of thought and action; that (*d*) it is an example of a developing tradition, eager for novelty but tenacious of established truth; that (*e*) it needs freedom as well as some respect for authority, and that (*f*) it is in part a social and in part a personal enterprise. A further characteristic peculiar to science is that (*g*) scientific life needs manual skill as well as intellectual.

I suppose that when a man has a 'bent' towards science the reason is that his temperament and abilities fall in with this particular version of rational life. He likes the solidity of the data of science, the balance of fact and theory, the ease with which they are cross-checked. He likes the unending novelty of interpretation against the firm background of fact; the balance of change and stability, of settled presuppositions and new movements breaking their bonds. He likes the blend of freedom to put forward new evidence and any theory it will bear, with constraint due to the authority of old and proved results. He enjoys the balance of manual and intellectual work. If he is that rare being, a master scientist, he enjoys the balance of hard reasoning with intuition and imagination in making creative advances. Now, if scientific life is a version of rational life, it can be to some extent used as a school of rational life; it may be used to exhibit some of the principles of rational procedure in general. Its special qualification for this purpose (which is also an expression of its limitations) is that it does not require a mature wisdom or knowledge of the world, yet it introduces the mind to logical thought, and insists upon the need for experience and for complete fidelity to it when theorizing. Moreover it suggests problems which can only be solved philosophically—the problem of the validity of its own method, for instance. Science and wisdom, then, should not be wholly unconnected in a scientist's life.

It is not only the intellect that can be developed by scientific life, however, but the will as well. Science imposes a discipline that can leave as strong a mark on the character as can its stimulation on the intellect. Science, like all intellectual work, demands (to quote von Hugel) 'courage, patience, perseverance, candour, simplicity, self-oblivion, continuous generosity towards others, willing correction of even one's most cherished views.'[3] Again, like all learning, science demands a twofold attention, to brute facts and to the synthetic interpretation of them; and so it forbids a man to sink into himself and his selfish claims and shifts the centre of interest from himself to outside. But for scientists there is a special and peculiar discipline. Matter is perverse and difficult to make behave as one wants; the technique of experimental investigation is a hard and chastening battle. Nature seems not to care whether we can understand her or not; she hides her secrets, and her facts are great slayers of theories. It is in this contact with 'brute fact and iron law' that von Hugel found the basis of a modern and scientific asceticism, and in submission to this discipline that he found the detaching, de-subjectifying force that he believed so necessary to the good life.

Science, then, can help to stimulate the intellect and to discipline the will. To this extent it has bearings on the good life. But it cannot do this work alone: it must take its proper place in a

[1] F. Sherwood Taylor, *The Fourfold Vision*, chap. 6.
[2] ENDEAVOUR, April 1946.
[3] *Mystical Element of Religion*, ii, 349.

liberal education and an open culture. The right use of science as a school of rational life depends on its being set in a matrix of other studies and other activities. Science by itself throws no light on its own value, nor on values in general. It is not a royal road to knowledge of every kind.

The upshot of this discussion, then, is this. Science, like other intellectual disciplines, has its own beauty and plays a part in revealing to us the beauty of nature. It is not unrelated to wisdom, though not wisdom itself. It can be integrated into the good life, though itself providing none of the principles of the good life. At every turn scientific life depends upon disciplines other than science. Without a liberal culture we shall miss most of the significance of science. The relevance of these conclusions to current thought on the place of science in human life is evident.

Book reviews

METALLIC CORROSION

Metallic Corrosion, Passivity and Protection, *by Ulick R. Evans, with an appendix by A. B. Winterbottom. Pp. xxxiv + 863. Edward Arnold, London. Second edition,* 1946. 50*s. net.*

That a second edition of this work should be required within eight years of its reprint speaks well both for author and scientific public. The volume is nearly 150 pp. larger than the earlier edition, but war-time reduction in the quality of the paper has roughly halved the thickness of the book. This makes it distinctly more convenient to handle, though the tendency of the type to show through is admittedly a disadvantage; but the publishers have made an excellent job of the obviously inferior materials at their disposal. All the same, a few plates illustrating various types of corrosion, micrographic structures, etc., would have relieved the puritanic text and broken the diagrammatic monotony. The book has been largely rewritten and much new material added, references as late as 1945 being included; this is excellent when one considers the long period that now elapses between proof-reading and publication. Apparently the detailed memoir of Logan and Romanoff, published in the United States in the autumn of 1944, did not reach England in time to be discussed in this book.

For the benefit of the non-academic reader a brief introduction to the principles of electrochemistry has been added to the forepart. Nine chapters are devoted to corrosion proper, four to protection, and one to methods of testing. One feels that the author might have done better by writing a separate volume on protective measures, as these are of great practical importance and deserve really thorough treatment. In the present volume the four chapters are inadequate, their chief value lying in their extensive bibliography. As part of a textbook, which is, apparently, the author's aim (*vide* p. iv), they are a failure. It is curious that under 'Random Errors' and 'Standard Error' (pp. 780–1), there should occur two of the very few grammatical errors in the volume. Generous acknowledgments are made to numerous authorities who have assisted the author in his arduous task.

J. NEWTON FRIEND

TREES IN BRITAIN

Trees in Britain, *by L. J. F. Brimble. Pp. x + 352. Macmillan & Company Limited, London.* 1946. 15*s. net.*

All those—and they must be very many—who read Mr Brimble's previous book *Flowers in Britain* will welcome this equally attractive successor. The British have always been tree-lovers, and here they and others will find much to charm them as well as instruct them. There are of course far fewer species of trees than of flowers in Britain, and this enables the author to make the treatment more detailed. The book is primarily intended for the general reader, and no knowledge of botany is assumed. Such botanical facts as are essential for the purpose are given in an introductory review of flowering plants. In the body of the book, the structure of trees, their classification, and their habits and habitats are considered, and special stress is laid on the part played by trees in folklore and literature. The colour plates have been prepared by artists who have specialized in painting trees, while some of the most attractive illustrations are reproductions of pencil drawings by the late Venerable Lonsdale Ragg. The book is well printed and produced and is decidedly one to possess.

CHROMATOGRAPHY

An Introduction to Chromatography, *by Trevor I. Williams. Pp. viii + 100. Blackie & Son Limited, London.* 1946. 10*s. net.*

The separation and purification of organic compounds by the method of chromatography is rapidly becoming of major importance in general laboratory practice. This book, written by one who has had considerable experience of the technique, is intended primarily for the student but will prove of equal value to research workers, who will readily find the information they normally require. Those desiring more detailed treatment of the subject will turn to the earlier monographs by Zechmeister and Cholnoky (English translation, 1941) and Strain (1942).

After a brief description of some of the pioneering work of Tswett on the separation of natural colouring matters over thirty-six years ago, an account is given of adsorbents, particularly alumina and its standardization, solvents, eluents used for the development of the columns, types of apparatus, and a considerable amount of information concerned with laboratory technique, illustrated by actual examples. The useful device of examining the columns in ultra-violet light is given due prominence, as is also the extension of chromatographic methods to the separation of colourless substances, including an account of the method of Tiselius. The separation of ions is a method of considerable potential value in inorganic analysis, and an account is given of the recent work of Martin and Synge on partition chromatography

using silica gel. The final chapter gives some consideration to the theory underlying chromatographic analysis. The book is admirably written, well illustrated, and attractively printed.

W. BAKER

THE BLEACHING OF TEXTILES

An Introduction to Textile Bleaching, *by J. T. Marsh. Pp. xiii + 512, with 154 figures, including 32 plates. Chapman & Hall Limited, London.* 1946. *32s. net.*

In *An Introduction to Textile Bleaching* the author has added yet another member to his excellent series of books on various aspects of textile chemistry and technology. It is a fitting companion to *An Introduction to the Chemistry of Cellulose* and *Mercerising*, and provides us with the first comprehensive review of a subject that has hitherto been scattered far and wide amongst the textile journals of the world.

The book is clearly written and thoroughly well organized, giving a valuable background of information in a form suitable either for the newcomer to the textile industry or for the experienced man who is progressive enough to be looking to science to help him in his work. The author has appreciated the importance of fundamentals, and devotes a considerable portion of his book to the structure of the various types of textile fibres; only when he has satisfied himself that this basic knowledge is sufficiently explained does he proceed to the discussion of textile bleaching itself. In this, Mr Marsh has set a precedent that could happily be followed up by other authors of this type of book; technical surveys are only too frequently spoiled by an inadequate discussion of first principles.

Today we are faced with an urgent problem in the modernization of the textile industry. The solution must, to a major degree, be dependent on the application of science and the scientific method in an industry that has grown up by rule-of-thumb procedure, and in order to do this we shall need efficient textbooks on textile science. Mr Marsh's series is helping to fill this void admirably.

J. G. COOK

A TEXTBOOK OF CHEMISTRY

General and Inorganic Chemistry for University Students, *by J. R. Partington. Pp. xxiii + 916. Macmillan & Company Limited, London.* 1946. *36s. net.*

Professor Partington is well known as an accomplished expositor of chemistry, and his textbooks are always characterized by the accuracy of their contents and their readable but unadorned style. The present book is intended for the higher forms at school and junior students at universities, and for degree students as far as inorganic chemistry is concerned; for honours students the author hopes the book will serve as a companion to their studies.

The earlier part of the book deals with general and physical chemistry, and gives among much other matter an excellent account of the quantum theory of the atom. The elements are then dealt with in the order of the groups in the Periodic Table. Though this order is not without its disadvantages, no-one has yet succeeded in finding a better one, and in any case there is of course a natural basis for the periodic arrangement.

As in his *Textbook of Inorganic Chemistry for University Students*, Professor Partington here includes descriptions of experiments for lecture demonstration, and also gives a useful list of books on lecture experiments. Details of technical processes are in general omitted, and only modern processes are described except when an old process has some scientific interest. Numerous references to original papers and other sources are given, and the importance to all students of consulting some original papers is rightly emphasized. The amount of information in the book is very large, but it is so lucidly presented that the student will find no difficulty in assimilating or using it.

BIOCHEMICAL MICRO-ANALYSIS

Micro-Analysis in Medical Biochemistry, *by E. J. King. Pp.* 168. *J. & A. Churchill Limited, London.* 1946. *10s. 6d. net.*

This book contains plain and precise instructions for the execution of all the routine biochemical investigations and analyses likely to be required in the pathological laboratory, including the preparation of reagents and the calculation of results. The book is more complete than its title might suggest, for some of the procedures, e.g. for urine, can hardly be classed as micromethods.

Apart from a table giving the 'normal' values for certain constituents of body fluids and faeces, another listing the clinical conditions associated with high or low values, and an occasional note in the text, there is no discussion of the interpretation of the findings. This is not to be expected, and in no way detracts from the book. Although the instructions are excellently clear and adequate, little or nothing is said of the limitations of the methods described, and references to fuller descriptions are rather scanty. The book is therefore not primarily for the student or for the clinician, but will be invaluable to all those actually examining or analysing clinical material.

The book is well produced, with pleasantly large type, and has useful chapters on colorimetric methods, simple spectroscopic procedures, and tests of function. It will certainly find a place on the shelf of every pathological laboratory.

N. G. HEATLEY

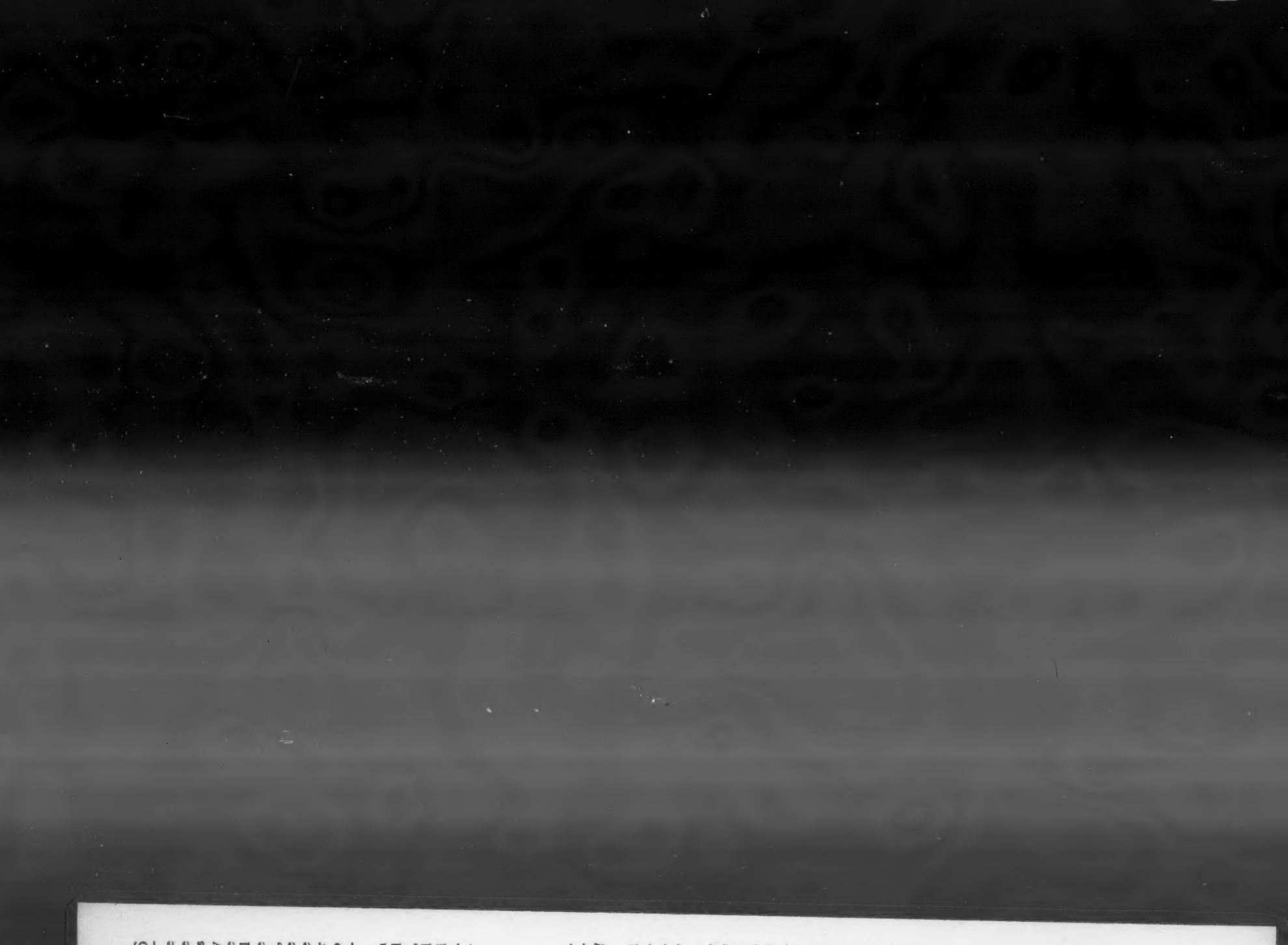
PHASE DIAGRAMS FOR AQUEOUS SOLUTIONS

Aqueous Solution and the Phase Diagram, *by Frederick Field Purdon and Victor Wallace Slater. Pp. iv + 168. Edward Arnold, London.* 1946. *24s. net.*

In this very pleasingly produced work, the authors explain the construction of the phase diagrams of heterogeneous systems, and discuss very clearly and fully their interpretation. It is shown how, merely from a knowledge of geometrical principles, phase diagrams can be used to solve, both qualitatively and quantitatively, problems relating to the separation of pure substances from mixtures, the preparation of double compounds and hydrates, the cyclic re-use of mother liquors, the right amount of evaporation or dilution required to give the best economic result consistent with purity of product, and the effect of the addition of other salts or the accumulation of impurities. From these diagrams the progress of the various operations can be followed quantitatively and the optimum conditions ascertained. Only aqueous solutions, however, are here discussed.

For the practical worker, this book should prove of great value. The diagrams are clear and excellently drawn, and tables of experimental data are given from which the student can construct his own diagrams. The book can be heartily recommended, though the concluding chapter on Gibbs's Phase Rule is probably too short to be of much value.

ALEXANDER FINDLAY



Notes on contributors

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Was born in 1892 and was educated at Simon Langton School, Canterbury, and the Royal College of Science, University of London. From 1914 to 1915 he was assistant to Sir Norman Lockyer at Sidmouth Observatory; from 1915 to 1919 he served with the Royal Flying Corps. He then joined the Meteorological Office of the Air Ministry, but in 1928 transferred to the Chemical Defence Research Department of the War Office. In 1938 he returned to the Air Ministry as Director of the Meteorological Office, a position he still holds.

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Was born at Brixton, London, in 1890, but spent his early life at Plymouth, where, after leaving school, he was for some years employed by the local education authority. In 1915 he entered the Royal College of Science, London, as a student of physics, and after graduating remained at the college as Lecturer, Assistant Professor, and Professor of Natural Philosophy. He is a member of many British and foreign learned societies, and has been secretary and vice-president of the Royal Astronomical Society. In 1936 he was Lowell Lecturer at Boston, U.S.A., and in 1927 and 1932 was a member of the British Government Eclipse Expeditions (the 1940 expedition, of which also he was a member, was cancelled). His scientific work has been chiefly concerned with spectroscopy (especially in its applications to astronomy and medical and industrial problems), relativity, and the philosophical aspects of science. He has recently been appointed Professor of History and Philosophy of Science at University College, London.

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Was born in 1891 and was educated at Hampton Grammar School and Merton College, Oxford. Since 1913 he has been on the staff of the National Physical Laboratory at Teddington, in the photometry section. He has a wide interest in problems relating to lighting, and has been a member of departmental committees on Ships' Navigation Lights, Lighting in Factories and Workshops, and Street Lighting. He was formerly secretary of the International Commission on Illumination. He is a member and a past president of the Illuminating Engineering Society. During the war of 1914–18 he was co-inventor with Sir Clifford Paterson of the Paterson-Walsh electrical height-finder. His work has been recognized by the Royal Photographic Society by the award of the Hurter and Driffield Medal. Besides many papers on photometry and illuminating engineering he has written several books: *Elementary Principles of Lighting and Photometry*, *Photometry*, *The Indexing of Books and Periodicals*, and *A Textbook of Illuminating Engineering* (in the press).

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Was born in 1894 and was educated at the University of Bristol. During the first world war he served with the infantry and the Balloon Observation Corps in France and Palestine. He has been associated with the Bristol Museum and Art Gallery since 1920, his first appointment being as Curator in Geology. He later became Deputy Director and was recently appointed Director of the City Museum, which has been separated from the Art Gallery for administrative purposes. His geological publications include papers on the Old Red Sandstone of the Bristol district, petrological examination of Neolithic and Bronze Age axes, and fossil insects. Dr Wallis's service with the Museums Association as Honorary Editor has brought him into contact with many phases of museum activities, especially since 1941, when he became actively interested in the production of the *Museums Journal*. He is particularly interested in Folk Museums and hopes that his future administrative work will include the establishment of a Folk Museum and Park near Bristol.

NEIL CAMPBELL,
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Was born in Edinburgh in 1903 and was educated at George Watson's College and Edinburgh University. After graduation he became a demonstrator in the Chemistry Department of the University, and in 1931 was appointed lecturer in Organic Chemistry. In 1930–1 he carried out research work under Meisenheimer at Tübingen, and in 1933–4 was Exchange Lecturer at Duke University, North Carolina. His research has included work on naphthalene, carbazole, benzanthrone, etc. His book *Qualitative Organic Chemistry* is well known, and he edited the new edition of Schmidt-Rule's *Organic Chemistry*.

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Was born in 1914 and was educated at St. Paul's School and The Queen's College, Oxford. After a distinguished academic career, which ended with a year devoted to the study of philosophy, he turned to research in physical chemistry. In this field his main interest is in the kinetics of reaction in solution, with particular reference to acid-base catalysis. From 1941–45 he was engaged in research for the Pyrotechnics Section of the Armaments Research Department. In October 1945 he took up an appointment as lecturer in physical chemistry at the University of Leeds. Besides chemistry his main academic interest is in philosophy, particularly in relation to science.

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